ALKÜ Fen Bilimleri Dergisi 2019, Özel Sayı (NSP 2018): 188-194

Correlation between Soil Gas Radon Concentrations and Terrestrial Radioactivity (U-238 and Th-232) in Afyonkarahisar

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Abstract

Humans are exposed both to natural radiation from the radioactive elements that have existed in the earth's crust since the formation of the earth and to artificial radiation from medical applications and sparrows after nuclear tests. The most important part in natural radiation affecting human beings is radon derived from terrestrial radioactive elements of Uranium and Thorium. Terrestrial radiation level is strictly related to the contents of Thorium (^{232}Th), Uranium (^{238}U) and Potassium (^{40}K) in rocks which is the origin of the soil in an area, and to the geological composition of the area.
The determination of natural background radiation levels is of great importance for all living things. In order to determine whether the living zone is healthy in terms of natural radiation, the concentrations of the radionuclides in the surrounding environment and the effects of radiation on all the living things must be known. In this study, it was aimed to determine the terrestrial background radiation level on the soil surface, and to evaluate the correlation between the Uranium and Thorium concentrations and the soil gas radon activity values in Afyonkarahisar city center.
Keywords: Terrestrial radioactivity, Uranium, Thorium, Radon, Soil, Afyonkarahisar

1. INTRODUCTION

Exposure to ionizing radiation coming from both natural and artificial radionuclides is inevitable for all living organisms. Natural radionuclides are present in all environments (air, water and soil), which come from both terrestrial and cosmic radiation. There are over 20 naturally occurring radioactive elements, however the major contribution to the terrestrial radiation comes from the primordial radionuclides: ^{238}U and ^{232}Th series and ^{40}K. Therefore, terrestrial radiation level is strictly related to the contents of Thorium (^{232}Th), Uranium (^{238}U) and Potassium (^{40}K) in rocks which is the origin of the soil in an area, and to the geological composition of the area [1].

Terrestrial radiation is emitted from natural radionuclides present in varying amounts in soil, air, water and other environmental materials [2]. In order to determine whether the living zone is healthy in terms of natural radiation, the concentrations of the radionuclides in the surrounding environment must be known. Since the determination of natural background radiation levels is of great importance for all living things, there have been several works performed to measure terrestrial activity concentration in different environments [3-7].

The most important part in natural radiation affecting human beings is radon derived from terrestrial radioactive elements of Uranium and Thorium. Radon is colorless, odorless, tasteless, and chemically inert radioactive gas, and not affected by chemical processes. There are three naturally occurring isotopes of radon:

- Rn-222 (radon) is the isotope with a half-life of 3.82 days and the product of Uranium (U-238) decay chain. It causes the most concern, because of the natural abundance of Uranium in the earth's crust and the health effects of its further decay products.

- Rn-220 (thoron) is the isotope with a half-life of 55.6 seconds formed in the decay chain of Thorium (Th-232).

- Rn-219 (actinon) is the isotope with a half-life of 4 seconds formed in the decay chain of Actinium (U-235).

The ^{222}Rn and ^{220}Rn can freely move through soil pores and rock fractures and then escape into the atmosphere [2]. The migration and concentration of radon and thoron in an anisotropic medium, such as bedrock, is highly variable and dependent upon the rock type, the physical condition of the rock (i.e., fractures, joints, and porosity), the aquifer parameters, and the aquifer geochemistry [8,9]. Natural radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions appear at different levels in each region in the world [10].

Due to the radiological health effects it is a great interest to define the level of radon concentration in all environments which is formed by radon and thoron emission from soil, rocks and degassing from water [11]. The internal irradiation of lungs by alpha-emitting short-lived decay products of radon and thoron cause lung cancer [12].

Since ^{222}Rn and ^{220}Rn are the products of ^{238}U and ^{232}Th, respectively, it is generally expected that the exhalation rates of ^{222}Rn and ^{220}Rn are relatively high at a site where ^{238}U and ^{232}Th are high, too [13]. In this study, it was aimed to determine the terrestrial background radiation level on the soil surface, and to evaluate the correlation between the Uranium and Thorium concentrations and the soil gas radon activity values in Afyonkarahisar city center.

2. MATERIALS AND METHOD

The present study was carried out in the midwest Anatolian city of Afyonkarahisar province at 65 sampling points. Terrestrial radioactivity measurements were done using a portable hand-held gamma-ray spectrometer and radon activity concentration in soil gas was measured by using the AlphaGuard PQ 2000 radon monitor.

2.1 Terrestrial Radioactivity Measurements

Portable gamma-ray spectrometers are widely used for natural radioelement mapping in the field studies. They monitor the energy channels centered at 1461 keV (^{40}K), 1765 keV (^{214}Bi) and 2615 keV (^{208}Tl) photo-peaks, for the estimation of K, U and Th concentrations, respectively. In the gamma spectrometry measurements, the estimation of the Potassium concentration in rocks and soils by gamma ray spectrometry is through the detection of 1461 keV gamma rays emitted by ^{40}K. ^{40}K occurs in nature as a fixed ratio to other, non-radioactive, isotopes of Potassium. Thus, the estimation of K is direct, and results are reported in % K (percent potassium). The estimation of Uranium is through detection of 1765 keV gamma rays of

^{214}Bi, a daughter product in the ^{238}U disintegration series. The estimation of Uranium by gamma ray spectrometry is thus indirect, and the results are reported in ppm eU (parts per million of equivalent Uranium). The equivalent is a reminder that the estimation is made in basis on the assumption of radioactive equilibrium in the ^{238}U decay series. Similarly, estimation of Thorium is through detection of 2615 keV gamma rays of ^{208}Tl, a daughter product of ^{232}Th decay series, and estimates are reported in ppm eTh (parts per million of equivalent Thorium). For geological purpose, the amount of Potassium is normally expressed in percent while Thorium and Uranium in parts per million (ppm). For the environmental radioactivity measurement, the amount of Potassium, Thorium and Uranium is normally expressed in Becquerels (Bq) per unit mass. The International Atomic Energy Agency (IAEA) gives the following conversion factors from concentration unit to activity unit in Bq.kg^{-1} [14, 15]:

- 1% Potassium = 313 Bq.kg^{-1} of ^{40}K,
- 1 ppm of Thorium = 4.06 Bq.kg^{-1} of ^{232}Th,
- 1 ppm of Uranium = 12.35 Bq.kg^{-1} of ^{238}U.

In this study, 1024-channel spectrometer with bismuth germanium oxide (BGO) detector was used for mapping of the surface concentration of the natural radioelements (FIG. 1). Working principle of the spectrometer is based on capture of gamma-rays in perfect quality BGO detector, with connected 1024-channel spectral analyzer. Calibration of the spectrometer is performed using great volume K, U, Th and background standards, according to IAEA (International Atomic Energy Agency) recommendation. Measurements were taken for 300 seconds and repeated three times at each point. At the same time the coordinates were also recorded using a GPS equipment.

FIG. 1. Portable BGO gamma detector

2.2 Soil Gas Radon Activity Measurements

Soil gas radon activities were measured by using the AlphaGuard PQ 2000 radon monitor equipped with a specially designed soil gas unit consists of a drilling rod with an exchangeable drilling tip with airlock which is closed by a rivet and capillary probe. The soil gas was sucked out from the surrounding ground area of a 0.7-m depth hole and pumped with a low flow rate mode into the ionization chamber of the monitor through the capillary probe. The schematic view of the experimental setup is presented in FIG. 2. In order to determine ^{222}Rn activity only, the ionization chamber was kept closed tightly after filling it with soil gas for about 10-minute time interval that is needed to neglect the thoron contribution. Detailed information about the experimental setup was given in various previous studies [16-18].

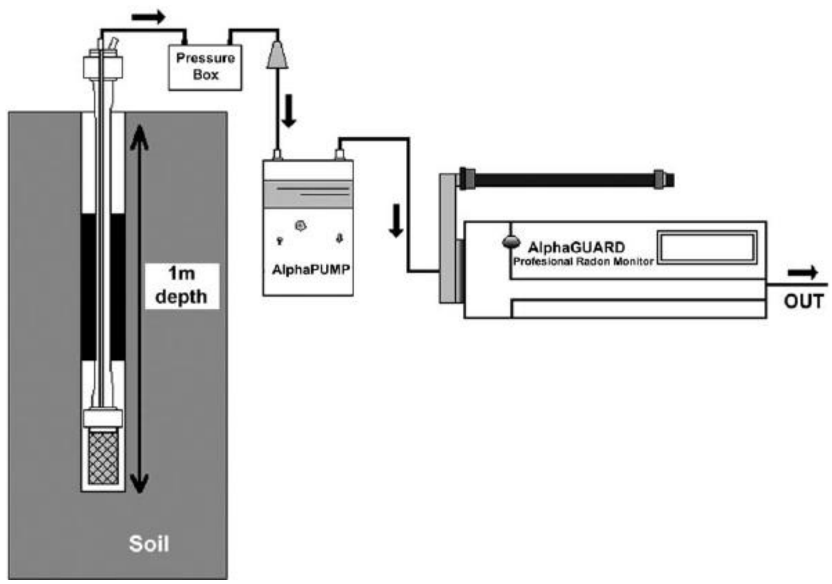

FIG. 2. Schematic view of experimental setup of soil gas radon measurement

3. RESULTS AND DISCUSSION

The activity concentrations of ^{238}U and ^{232}Th, and soil gas radon concentrations have been separately measured at 65 sampling points in Afyonkarahisar city center. ^{238}U and ^{232}Th activity measurements were done at 30 cm above soil surface, whereas soil gas radon measurements were carried out in 0.7 m depth holes. The obtained results are shown in TABLE I where the Uranium activity concentration varies from a minimum value of 2.69% ppm to a maximum value of 15.77% ppm and its average value is 7% ppm, moreover the Thorium activity concentration ranges from a minimum value of 3.2% ppm to a maximum value of 29.66% ppm and the average Thorium activity value is 15% ppm. On the other hand, soil gas radon concentrations are ranged from 8.7 to 186.1 kBq.m^{-3} with the average value 55.45 kBq.m^{-3}.

The average activity values of ^{232}Th and ^{238}U were calculated using the IAEA regulations given in ref. [14]. The present average activity values of 60.9 Bq.kg^{-1} for Thorium and 86.45 Bg.kg^{-1} for Uranium are well above the world average values (30 Bq.kg^{-1} for Thorium and 35 Bq.kg^{-1} for Uranium) defined by the UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiations) in Ref. [2].

TABLE I. Terrestrial radioactivity (^{238}U and ^{232}Th) and soil gas radon activity concentrations

	Concentration values (% ppm)			Average activity (Bq.kg^{-1})
	Minimum	Maximum	Average	
Thorium	3.2	29.66	15.0	60.9
Uranium	2.69	15.77	7.0	86.45
	Concentration values (kBq.m^{-3})			
	Minimum	Maximum	Average	
Radon	8.7	186.1	55.45	

Correlations between the Uranium and Thorium activities, and the soil gas radon activity were investigated for the present survey. As it can be seen in FIG. 3, there is an acceptable correlation between Uranium and Radon activities in accordance with the expectation for which the exhalation rate of ^{222}Rn should be high in a site where ^{238}U is high. On the other hand, it seems that there is no correlation between Thorium and Radon activities in the present work, since thoron activity contributions not included during soil gas radon activity measurements or not measured separately (FIG. 4).

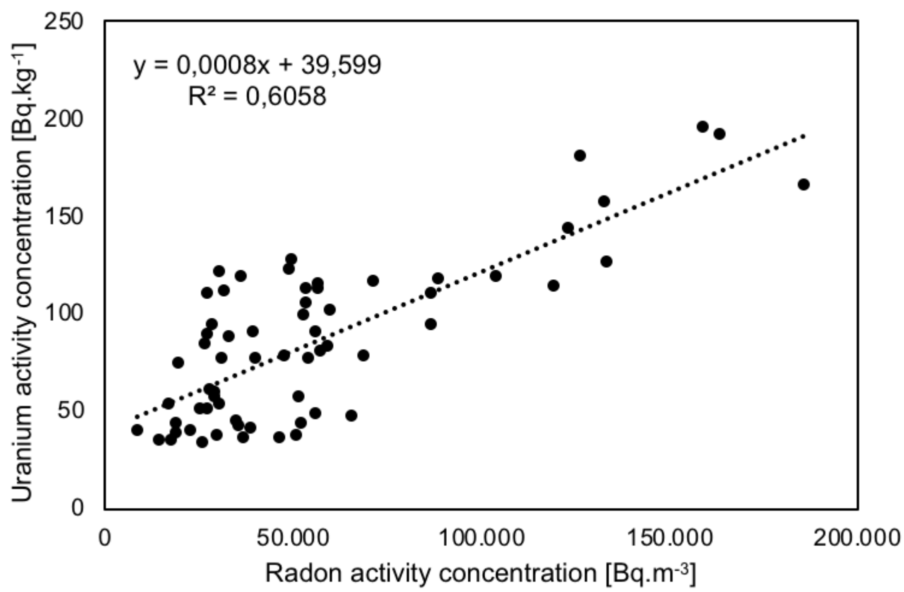

FIG. 3. Correlation of Uranium and radon activity concentrations in soil

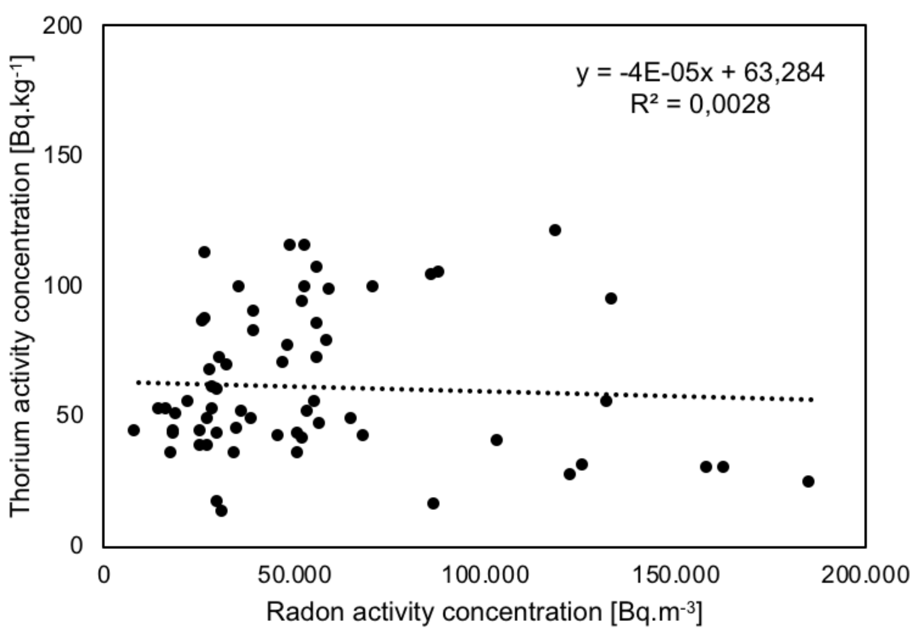

FIG. 4. Correlation of Thorium and radon activity concentrations in soil

4. ACKNOWLEDGEMENTS

This work was supported by Afyon Kocatepe University Science Research Projects Coordination Unit with the grant numbers [14.FEN.BİL.08] and [18.KARİYER.151].

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