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ENVIRONMENTAL RADIOACTIVITY MEASUREMENTS IN BARTIN PROVINCE, NORTH-WEST OF BLACKSEA REGION

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KUZEY ANADOLU BÖLGESİNDE BULUNAN BARTIN İLİNDE ÇEVRESEL RAYOAKTİVİTE ÖLÇÜMLERİ

Abstract:

The aim of this study is to determine the background radioactivity levels and assess the relevant health risks for Bartın province located north coast of Turkey. For this purpose the collected soil samples were analyzed by the method of gamma spectrometry, outdoor gamma dose rates were investigated by in-situ measurements and the collected drinking water samples were analyzed by proportional counter with gas flow. The average activity of radionuclides ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs in soil were determined as 20.2±7.3, 26.9±10.5, 445±175, 6.4±6.4 Bq kg^{-1} respectively for Bartın province. The mean outdoor absorbed gamma dose rate was measured 1 m away from the ground as 56±15 nGy h^{-1} for the region. The average gross alpha and beta activity for drinking water were found to be 0.039±0.048 and 0.135±0.403 Bq L^{-1} respectively. The average annual effective dose value due to cosmic, terrestrial radiations and alpha-beta activity in water was calculated as 0.03±0.01, 0.04±0.01 and 0.02±0.03 mSv respectively for people living in the region. Spatial distribution map of each radiologic parameter plotted for the region is presented in the paper.

Özet:

Bu çalışmanın amacı, Türkiye'nin kuzey sahilindeki Bartın ili için fon radyoaktivite düzeylerini belirlemek ve ilgili sağlık risklerini değerlendirmektir. Bu amaçla toplanan toprak örnekleri gama spektrometresi yöntemi ile analiz edilmiş, dış ortamdaki gama doz oranları yerinde ölçümlerle araştırılmış ve toplanan içme suyu örnekleri gaz akışlı orantılı sayaç ile analiz edilmiştir. Topraktaki ^{226}Ra, ^{232}Th, ^{40}K ve ^{137}Cs radyonüklitlerinin ortalama aktivitesi, Bartın ili için sırasıyla 20,2 ± 7,3, 26,9 ± 10,5, 445 ± 175, 6,4 ± 6,4 Bq kg^{-1} olarak belirlenmiştir. Bölge için ortalama yerden 1m yükseklikte havada absorbe edilen gama doz hızı, 56 ± 15 nGy h^{-1} olarak ölçülmüştür. İçme suyu için ortalama toplam alfa ve beta aktivitesi sırasıyla 0,039 ± 0,048 ve 0,135 ± 0,403 Bq L^{-1} olarak bulunmuştur. Bölgede yaşayanlar için kozmik, karasal radyasyonlar ve sudaki alfa-beta aktivitesine bağlı ortalama yıllık efektif doz değerleri, sırasıyla, 0,03 ± 0,01, 0,04 ± 0,01 ve 0,02 ± 0,03 mSv olarak hesaplanmıştır. Her bir radyolojik parametrenin bölge için çizilen dağılım haritası makalede sunulmaktadır.

Keywords: Bartın, cancer risk; radionuclide; gamma dose rate; gross alpha; gross beta; biological effective radiation dose

Anahtar Kelimeler: Bartın, kanser riski; radyonüklid; gama doz hızı; toplam alfa; toplam beta; biyolojik etkin radyasyon dozu

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1. Introduction

The environment is an essential element of human existence. It is a result of interference of natural elements -earth, air, water, climate, biosphere-with elements created by human activity (Huseyinli, Hajiyeva, Yolchiyeva & Nazarov, 2016). Accumulation of naturally occurring radioactive elements or compounds in the environment might cause very serious health problems for people. Therefore, it is important to determine background radiation levels in the environment to prevent possible health risks.

There are two main contributors to natural radiation exposures: high-energy cosmic ray particles incident on the earth's atmosphere and radioactive nuclides that originated in the earth's crust and are present everywhere in the environment, including the human body itself. Cosmic rays interact with the nuclei of atmospheric constituents, producing a cascade of interactions and secondary reaction products that contribute to cosmic ray exposures that decrease in intensity with depth in the atmosphere, from aircraft altitudes to ground level. Naturally occurring radionuclides of terrestrial origin (also called primordial radionuclides) are present in various degrees in all media in the environment, including the human body itself (UNSCEAR, 2000). As a result of nuclear explosions carried out in the earth's atmosphere and the nuclear power station accidents, the world has become polluted with radionuclides of artificial origin. Some of these long-lived isotopes ^{134}Cs ($T_{1/2}$ = 2 y) and ^{137}Cs ($T_{1/2}$ = 30 y) exist in surface soil, as a result of the radioactive fall-out from the atmosphere (Orgun et al, 2007). Exposure of cells and organisms to background radiation may cause DNA damage. The cellular processing of radiation-induced damage to DNA by enzymes may result in a return to normal sequence and structure, or processing may fail or may cause alterations in DNA that lead to lethality or heritable changes (mutations and chromosomal aberrations) in surviving cells (Kapdan et al., 2011).

Because of the detrimental effects of the background radiations to the human body, various studies have been performed, particularly in urban areas, to prevent possible health hazards. Hence, the objective of this study is to evaluate and map radiologic parameters and also to assess the relevant health risks for Bartın province located in the North-West of Blacksea region.

2. Survey Area

Bartın province located in North-West of Blacksea Region of Turkey is chosen as research region for the study. The province with the population of 192.817 has area about 2,076 km^2 as can be seen in Figure 1. The city center is located at the geographic coordinates of 41° 38' 15.3744" N and 32° 20' 1.7268" E. Bartin is surrounded by mountains not more than 2000 m in height from the east, west and north and forests form 46% of Bartin. There are numerous ancient city ruins inside the borders of historic Paphlagonia region of Bartin. Ancient cities of Sesamos (Amasra), Kromna (Kurucasile) and Erythinoi (Cakraz) are located also in the province. The second nuclear power plant planned to be constructed in Sinop will be located very close to the region.

3. Materials and methods

The activity concentration of radionuclides was determined by gamma spectrometric analysis of the collected soil samples, outdoor gamma dose rates were investigated by in-situ measurements and the collected drinking water samples were analyzed by proportional counter with gas flow. The geographic coordinates of the stations were determined by Global

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Positioning System (GPS).ArcMap module of ArcGIS (10.2 version) mapping software was used for plotting spatial distribution maps for the region.

3.1. Determination of soil radioactivity and terrestrial gamma dose rate

Soil samples were obtained from uncultivated locations that were close to settlements. Open, flat and undisturbed geographical locations which had good water permeability were selected as the sampling points. The foreign bodies were removed and the remaining soil was placed in clean, sealed and labeled bags. The samples were dried at 105°C for 24 h, grained, passed through 2 mm sieves and placed in Marinelli type beakers. The samples were kept one month before the analysis at the airtight condition to allow secular equilibrium between thorium and radium and their decay products. Each sample was counted for 50000 s using a gamma spectroscopy device connected to a coaxial HPGe detector, Canberra, in the accredited laboratories of Radioactivity Analysis and Measurement Department in Çekmece Nuclear Research and Training Center (CNAEM). The detector was shielded to reduce the background due to the cosmic rays and the radiation nearby the system. Full energy peak efficiency was determined using Standard Reference Material prepared by International Atomic Energy Agency (IAEA, 2000). The MDA (Minimum Detectable Activity) value for ^{137}Cs was obtained as 0.5 Bq kg^{-1}.

Based on the radioactivity levels of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs the gamma absorbed dose rate in air (ADRA) in nGy h^{-1} at 1 m above the ground level was calculated by using the following equation (UNSCEAR, 2000).

$$\textbf{ADRA} = aC_{Ra} + bC_{Th} + cC_{K} + dC_{Cs} \quad (1)$$

Where C_{Ra}, C_{Th}, C_{K} and C_{Cs} are the activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs, respectively, in soil sample. The values of a, b, c, and d are coefficients of 0.461, 0.623, 0.0417 and 0.1243 nGy h^{-1} (Bq kg^{-1})$^{-1}$, respectively (UNSCEAR, 2000; UNSCEAR, 2008).

3.2. Determination of outdoor gamma dose rates

The outdoor gamma dose rates were measured during the summer season. Therefore, the study was realized for the dry soil conditions of the region. In order to determine the outdoor gamma dose rates, the total of 133 readings was taken 1 meter away from the ground at the same stations soil sample collected, as demonstrated in Figure 3. The gamma dose rates were measured by the portable device (Thermo sci.) connected with high sensitivity NaI scintillation detector (NBR model of Thermo sci.) calibrated at the beginning of the study by accredited Secondary Standard Dosimetry Laboratory (SSDL) of Çekmece Nuclear Research and Training Center (CNAEM). The measurements were taken in the air for two minutes and the gamma dose rates were recorded as μR h^{-1} and then converted to nGy h^{-1}using the conversion factor of 8.7 nGy μR^{-1}. The annual effective dose equivalent (AEDE) (nGy h^{-1})was calculated by using the following equation (UNSCEAR, 2000).

$$\textbf{AEDE} = ADRA \times DCF \times OF \times T \quad (2)$$

where, DCF is dose conversion factor of 0.7, OF is occupancy factor of 0.2 and T is the time (8760 h y^{-1}). In addition, excess lifetime cancer risk value (ELCR) for 70 years of average life duration was calculated by using following equation (UNSCEAR, 2008).

$$\textbf{ELCR} = AEDE \times DL \times RF \quad (3)$$

where DL is the duration of life (70 y) and RF is the risk factor (Sv^{-1}), fatal cancer risk per sievert. For stochastic effects, RF of ICRP 103 for the public as 0.055 was used (ICRP, 2007).

3.3. Determination of radioactivity in drinking water

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The collected water samples at pre-determined stations were transported to the laboratory in 500 cm^3 plastic bottles. A routine procedure outlined by Karahan et al. was followed to prepare the samples for radionuclide analyses (Karahan, Öztürk & Bayülken, 2000). Each sample was first filtered through a paper and then transferred to a beaker where a small amount of nitric acid was added to avoid any precipitation on the walls of the container. After slow evaporation to near dryness, the sample was moved to a stainless steel counting planchette to be evaporated to dryness at low temperature. After cooling and weighing for the dry residue, each sample was counted for gross-alpha and gross-beta radioactivities in a low-background proportional counter with gas flow (Berthold, LB770-PC 10-Channel Low-Level Planchet Counter). The system was commonly used for measuring environmental samples with low natural background radiation. The results were obtained in units of Bq dm^{-3}. The calibration of the low-level counting system used in the measurements was carried out with standard solutions that contained known activities of ^{241}Am for alphas and ^{90}Sr for betas which were similar to the sample geometry. The following equation was used to calculate the effective dose (DR_W) due to drinking water radioactivity.

$$\mathbf{DR_W} = A_W \times IR_W \times ID_F \times 2 \text{ (for both } \alpha \text{ and } \beta) \quad (4)$$

where DR_W is the dose equivalent effective (Sv/year), A_W is activity (Bq L^{-1}), IR_W is the intake of water for one person in 1 year (730 L), and ID_F is the ingestion effective dose equivalent factor for 3.58×10^{-7}Sv Bq^{-1} for alpha (Kobya et al., 2015). Excess lifetime cancer risk value (ELCR) for 70 years of average life duration was calculated by using following equation.

$$\mathbf{ELRC} = DR_W \times DL \times RF \quad (5)$$

where DR_W is the annual effective dose equivalent (Sv/year), DL is the duration of life (70 years), and RF is the risk factor (Sv^{-1}). For risk assessment, the nominal probability coefficient of $7.3\times10^{-2}Sv^{-1}$ recommended by ICRP was adopted (Kobya et al., 2015; ICRP, 1991; Görür and Camgöz, 2014).

4. Results and Discussions

In order to determine the activity concentration of radionuclides in soil, the total of 65 soil samples was collected from pre-determined stations and analyzed. The average activities of radionuclides ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs were determined as 20.2±7.3, 26.9±10.5, 445±175, and 6.4±6.4 Bq kg^{-1} respectively in Bartın for the dried soil. Radionuclide activities determined for each sample station in the region are given in Table 1 and the distribution maps of each radionuclide are presented in Figure 2. The variation in activities of the natural radionuclides seen in the maps directly depends on the radiologic structure of the soil. Besides, ^{137}Cs activity was determined significantly higher in some parts of the region. ^{137}Cs is spread to the atmosphere through nuclear activities. Most of the fallout radiation accumulates in the soil (UNSCEAR, 1982). Turkey has been affected by the Chernobyl nuclear power accident in 1986 as other close countries to the area. Studies conducted after the accident pointed out to ^{137}Cs accumulation particularly at the north coast of Turkey and Thrace (Gokmen, Akgoz & Gokmen, 1996).

Outdoor gamma dose rates were obtained by readings at 133 stations and mean values were given for each district in Table 2. The spatial distribution map plotted for the outdoor gamma dose rates in the region was given together with the location of reading stations in Figure 3. The mean outdoor absorbed gamma dose rate, consisting of the terrestrial and the cosmic radiations, was measured 1 m away from the ground as 56±15 nGy h^{-1} for the region. The highest average dose rate was determined for the Amasra district. The average terrestrial gamma dose rate at 1 meter away from the ground, which was derived from the activity of radionuclides in soil using the equation (1), was calculated as 32.7±6.8 nGy h^{-1} for the region and it is observed that the terrestrial gamma dose rates vary considerably within the study area, even among the

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closest regions. This variation is associated with the varying concentration of the radionuclides depending on the soil structure. Moreover, the average dose rate due to cosmic radiation for the research region was calculated as 23.3±8.4 nGy h^{-1} subtracting the calculated terrestrial gamma dose rate from the measured gamma dose rate in air. Cosmic gamma dose rate mainly depends on altitude and weakly geomagnetic latitude of the regions (UNSCEAR, 2000). Therefore, the changes in cosmic radiation levels in the region could be explained by drastic changes of altitudes in the region as explained in the Survey Area section.

In order to determine the radioactivity levels in drinking waters, the samples were collected from 60 different locations in the research area and analyzed. The average gross alpha and gross beta activities were determined as 0.039±0.048 Bq L^{-1} and 0.135±0.403 Bq L^{-1} respectively for Bartın. The district of Amasra and Center have the highest mean gross alpha and mean gross beta activity in drinking water with 0.086±0.078 Bq L^{-1} and 0.123±0.044 Bq L^{-1} respectively. The values of gross alpha and beta activities determined for each sampling station are given in Table 3. Besides, the spatial distribution maps plotted for the gross alpha and gross beta activities of drinking waters in the region are given together with the location of sampling stations in Figure 4. The main reason for the variation of activities observed between different locations of the region seen in the maps is the change in the radiologic characteristic of underground origin of water resources and pathways.

The health effects of ionizing background radiations in the research region have been investigated by determining the biological effective radiation doses and the related cancer risks. The calculated annual biologic effective dose and the estimated excess cancer risk values due to radiologic exposure caused by terrestrial, cosmic radiation and radioactivity in drinking water are given in Table 4 for each district. The average annual dose value due to outdoor gamma radiation was calculated as 0.07±0.02 mSv for the region using equation (2). This value includes dose values of 0.03±0.01 mSv and 0.04±0.01 mSv due to cosmic and terrestrial radiations respectively. The determined dose values were considered for dry soil conditions and stated outdoor occupancy. These values could change depending on weather conditions, duration of exposure, humidity, the rate of fertilizer usage and the asphalt thickness above the soil. Cosmic radiation exposure dose values mainly depend on the altitude of the location. Therefore, due to changes of altitudes inside the region, travel and living in different parts of the region would directly affect the cosmic radiation exposure to people. Moreover, the average estimated excess cancer risk value due to outdoor gamma dose exposure was calculated as 2.57±0.70E-04 for the region using equation (3) with the risk factor determined in ICRP 103, however, risk values can change depending on methods and risk factors chosen (ICRP, 2007). Similarly, the annual cumulative effective dose for people living in the region due to radioactivity in drinking water was determined as 0.02±0.03 mSv for using the equation (4). Also, the average estimated excess cancer risk value related with this exposure was calculated as 1.18±1.46E-04 using the equation (5). This value may change depending on the factors mentioned above.

Finally, Table 5 is a list of background radiation studies conducted in other cities in Turkey. It is observed that ADRA value determined for the region is lower than the values determined for other cities. Moreover, mean ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs activity concentration values determined for the research region are seen to be compatible with those of other investigated cities and worldwide averages. In terms of radioactivity in water, while mean gross alpha value is between the values of other cities, gross beta is higher than the values determined in other cities. This shows that the water carried to the region comes from underground structures with relatively higher radioactivity.

5. Conclusion

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In this study, background levels of radionuclides were investigated in Bartın province close to the Sinop province where the second nuclear power plant will be constructed in the near future and this study revealed basic levels for the region before the plant is started. It was observed that almost all the radiologic parameters (radionuclide concentration in soil and alpha-beta activity in drinking water and value of outdoor gamma dose rate) determined for the region are compatible with other cities of Turkey investigated before. Besides, ^{137}Cs activity was determined significantly higher in some parts of the region. This should be related to fallout during Chernobyl NPP accident.

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