Dokuz Eylül Üniversitesi Mühendislik Fakültesi Fen ve Mühendislik Dergisi
Dokuz Eylul University Faculty of Engineering Journal of Science and Engineering

Basılı/Printed ISSN: 1302-9304. Elektronik/Online ISSN: 2547-958X

A Thoron Anomaly in the Soil Gas: A Case Study From Büyükorhan, Bursa, Turkey

Toprak Gazında Bir Toron Anomalisi: Büyükorhan, Bursa, Türkiye'den Bir Vaka Çalışması

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Geliş Tarihi / Received: 24.06.2021 *Araştırma Makalesi/Research Article*
Kabul Tarihi / Accepted: 07.08.2021 *DOI:10.21205/deufmd.2022247015*
Atıf şekli/ How to cite: AKKAYA, G.(2022).A Thoron Anomaly in the Soil Gas: A Case Study From Büyükorhan, Bursa, Turkey.DEUFMD, 24(70), 157-164.

Abstract

The main sources of radiation exposure are the inhalation of radon, thoron and their decay products released from the rocks and soil, and terrestrial gamma radiation. In order to estimate the potential effects, the radon and thoron concentrations in the soil gas, the radon measurements in the groundwaters and outdoor gamma dose rates were measured at 18 different locations in Büyükorhan in the south of Bursa, which granitoid unit takes up a vast space in this area. The radon and thoron concentrations in the soil gas were found to vary from 0.54 ± 0.01 kBq m^{-3} to 36.25 ± 0.98 kBq m^{-3} (mean value 11.54 ± 2.79 kBq m^{-3}) and from 14.86 ± 1.21 kBq m^{-3} to 1462.50 ± 26.47 kBq m^{-3} (mean value 174.53 ± 87.35 kBq m^{-3}), respectively. The measured radon concentrations in the groundwater samples ranged from 6.89 ± 1.11 to 61.43 ± 0.55 Bq l^{-1} (mean value 24.85 ± 4.36 Bq l^{-1}). The measured outdoor gamma dose rates varied from 68 nGy h^{-1} to 369 nGy h^{-1} (mean value 129.7 nGy h^{-1}). It was observed that radon and thoron concentrations in the soil gas are controlled by the lithology of the region. Additionally, the effect of the radon and thoron concentration in soil gas on outdoor gamma dose rate is indicated in the present study.

Keywords: *Radon, Thoron, Groundwater, Soil gas, Outdoor gamma dose rate*

Öz

İnsanların maruz kaldıkları ana radyasyona kaynakları, kayalardan ve topraktan salınan radon, toron ve bunların bozunma ürünlerinin solunması ve yersel gama radyasyonudur. İnsanlar üzerindeki olası etkilerini tahmin etmek için, granitoyid biriminin geniş bir alanı kapladığı Bursa'nın güneyindeki Büyükorhan'da 18 farklı lokasyonda toprak gazındaki radon ve toron konsantrasyonları, yeraltı sularındaki radon ölçümleri ve dış mekan gama doz oranları ölçülmüştür. Toprak gazındaki radon konsantrasyonlarının 0,54 ± 0,01 kBq m^{-3} ile 36,25 ± 0,98 kBq m^{-3} (ortalama değer 11,54 ± 2,79 kBq m^{-3}) arasında ve toron konsantrasyonlarının 14,86 ± 1,21 kBq m^{-3} ile 1462.50 ± 26.47 kBq m^{-3} (ortalama değer 174.53 ± 87.35 kBq m^{-3}) arasında değiştiği bulunmuştur. Yeraltı suyu numunelerinde ölçülen radon konsantrasyonları 6.89 ± 1.11 Bq l^{-1} ile 61.43 ± 0.55 Bq l^{-1} (ortalama değer 24.85 ± 4.36 Bq l^{-1}) arasında değişmektedir. Ölçülen dış mekan gama doz oranları ise 68 nGy h^{-1} ile 369 nGy h^{-1} (ortalama değer 129.7 nGy h^{-1}) arasında

değişmektedir. Bölgenin litolojisinin, toprak gazındaki radon ve toron konsantrasyonları üzerinde etkili olduğu görülmüştür. Ayrıca bu çalışmada, toprak gazındaki radon ve toron konsantrasyonlarının dış mekan gama doz oranları üzerindeki etkisi de belirtilmiştir.
Anahtar Kelimeler: *Radon, Toron, Yeraltı suyu, Toprak gazı, Dış mekan gamma doz oranı*

1. Introduction

Due to differences in the geographical and geological structures of the region, the concentrations of the natural radionuclides uranium, thorium and potassium in rocks and soil vary substantially. The gaseous element ^{222}Rn (radon) of the uranium decay chain has long half-life decay products that increase human exposure to radiation, although it has a half-life of several days.

The decay products of the gaseous element ^{220}Rn (thoron), which has a short half-life of the thorium decay chain, also have a short half-life [1]. Radon and thoron atoms are released into rocks or into the pore space between soil grains. The amount of the parent isotopes, fracture distribution of the rocks, rock porosity, grain size, permeability, meteorological factors and soil moisture affect the radon and thoron transport and emanation in the soil [2]. Acidic magmatic rocks such as granite, syenite, rhyolite have higher radiation levels [3-5]. However, in many studies high concentrations of radon were measured near geological fault zones [6-8]. High radon values may be indicative of the enhanced permeability in which ^{222}Rn rapidly migrates to the surface before disintegrating into decay products. Rn / Tn (Rn; Radon, Tn; thoron) concentration ratio is a suitable indicator for detecting the presence of fracture or fault systems connecting the deep zone to the surface. Zones with high Rn / Tn ratios are indicative of both the existence of a fault / fracture zone and that the fault / fracture extends from deep zone to the surface [9]. The soil and rocks are the main contributors to the indoor radon and thoron concentrations [10]. Radon levels in the soil gas are used for radon risk assessment and mapping. The radon gas and its decay products in the atmosphere are particularly significant sources of exposure from natural radiation influencing members of the public harmfully.

Radon monitoring has a great interest in geophysical studies and knowledge of radiation doses received by population. Radon-potential maps have been produced in many different countries in order to identify the real health hazards that radon and its daughters can cause [11-14]. Turkish Atomic Energy Authority also prepared a report, which includes the results of the measurements on the determination of the radon activity concentrations in the houses [15].

To determine the radon potential of the soil and radon risk classes, the model suggested by Neznal et al. [16] was used for risk assessment of the soil radon, which is based on the determination of the radon concentration in the soil gas and permeability of the soil. Flowing groundwater interacts with the rock matrix through aquifers, and the radon passing through the soil and rock dissolves in the water.

The radon level in the water depends on physical factors such as the pH and temperature of the water [17]. Radon, a highly mobile and short half-life gas, is a useful time-tracer for hydrogeological systems with high flow velocities and short flow distances [18]. Due to the short half-life of radon, the radon content of deep-source water is produced by the radium content [19]. The high radon content of deeper groundwater sources with higher radon content due to additional water-rock interactions may be a good indicator of water circulation and underlying geology [20].

Human exposure to external radiation mainly arises from natural radiation sources of terrestrial and cosmic origin. The main purpose of radiation measurements is to determine the radiation dose that people are exposed to due to environmental sources. In addition to position-dependent changes, the outdoor gamma dose rate in air at any location is not constant and exhibits significant fluctuations, particularly due to rain, soil moisture and thermal changes in the air, especially of radon and its decay products [1].

This study represents the first comprehensive reports on the radon and thoron measurements in the soil gas, the radon measurements in the groundwaters and outdoor gamma radiation levels in Büyükorhan granitoid and surrounding rocks of the Büyükorhan township. The radon gas and its decay products are significant sources of natural environmental exposure. Because of short half-life, exposures to thoron and its decay products have often been generally ignored. According to effect of lithology of the region, we carried out a survey of radioactivity, focusing on radon and thoron concentrations in the soil gas in the southern part of Bursa. Additionally, this study exhibits the influence of such formations on the radon and thoron concentrations in the soil gas, radon concentrations in the groundwaters and outdoor gamma dose rate.

2. Description of the study area

The study area covers Büyükorhan located the south of the town of Bursa. In the vast area covering Büyükorhan township, there is a foundation consisting of Sırıl metamorphics, ophiolite formed by a tectonic overthrust on these foundation rocks and granodiorite rocks cutting these units. The foundation of the area is composed of Sırıl metamorphics. A general geological map and generalized stratigraphic section are shown in Figure 1. Sırıl metamorphics forming the foundation of the study area and its surroundings consist of metapelites and metabasite rocks. There is base conglomerate which consists of limestone and quartz pebble on Sırıl Metamorphics [21]. Orhaneli Ophiolite is formed by tectonic overthrust on Sırıl metamorphics. Orhaneli ophiolite, which is an important ophiolite complex of the İzmir-Ankara-Erzincan zone, is on the metamorphic foundation, and is mostly composed of dunite rocks. The calc-alkaline Büyükorhan granitoid, which was called as Orhaneli granodiorite in the previous studies, was tectonically inserted to the metamorphic foundation and ophiolite rocks [22]. The geochemistry of granodiorite was studied by Harris et al. [23]. This pluton has a uniform meta-aluminous composition with silica contents of 63-69% [24]. The calc-alkaline granites with high K and syenites are less common. The equigranular granodiorite is made up of plagioclase (50-60% by volume), quartz (20-25%), biotite (10-15%), alkali feldspar (~ 10%), and hornblende (~ 5%) [23]. Additionally, it consists of abundant microgranitoid enclaves and zircon, apatite and opaque as accessory minerals [25].

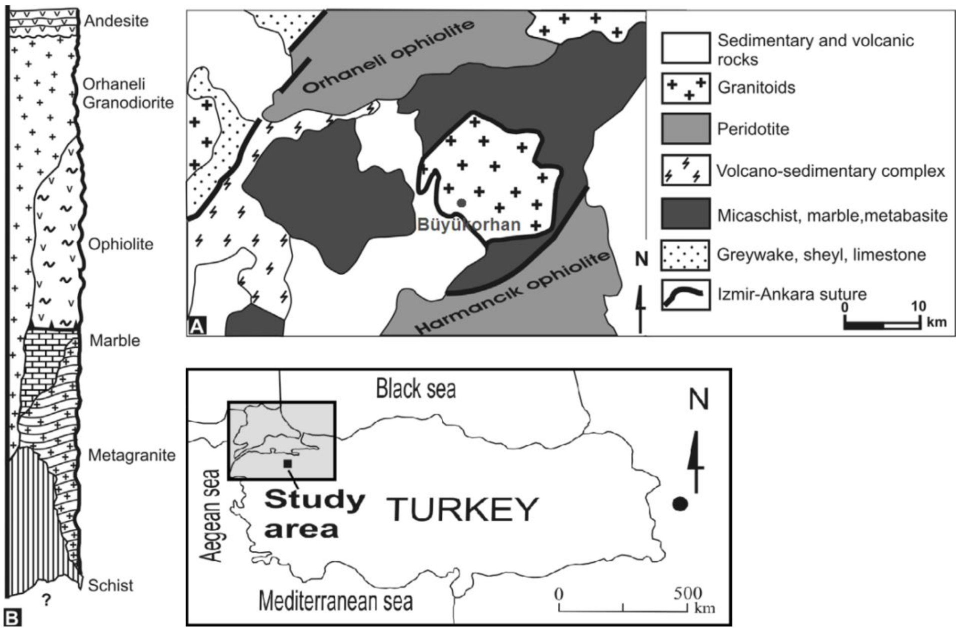

Figure1. Generalized geological map (A), stratigraphic columnar section (B) modified from Erginal and Ertek [25]

The SE-SW strike-slip faults and NW-SE directional reverse faults are formed in the region depending on the plutonite settlement [27]. The distributions of major faults and fractures were reported by Erginal and Ertekin [25]. The main soil types in the study area are non-calcareous brown forest soils and alluvial soils. These soils that are rich in organic matter are used for agricultural purposes [28].

3. Materials and methods

The radon and thoron activity concentrations in the soil gas were measured using an AlphaGUARD PQ2000 PRO ionization chamber (Genitron Inst.).

Figure 2 shows the schematic set-up of the AlphaGUARD radon-thoron monitoring of the soil gas.

Figure 3 is the representative plot of the data in the soil gas measured using the AlphaGUARD. The radon concentrations of the groundwater samples were also measured using the AlphaGUARD PQ 2000PRO.

Figure 4 shows the AlphaGUARD with the AquaKIT set-up for water measurements. Detailed experimental processes and methods for waters and soil gas were given in our previous study [29].

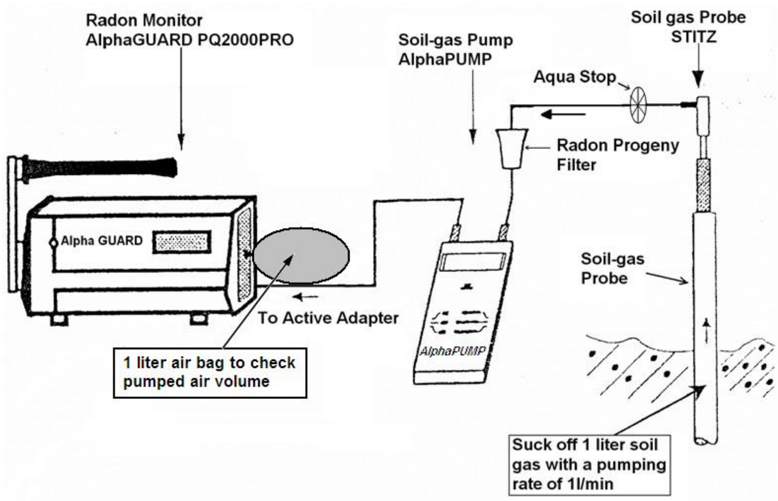

Figure 2. Schematic set-up of AlphaGUARD radon-thoron monitoring in the soil gas.

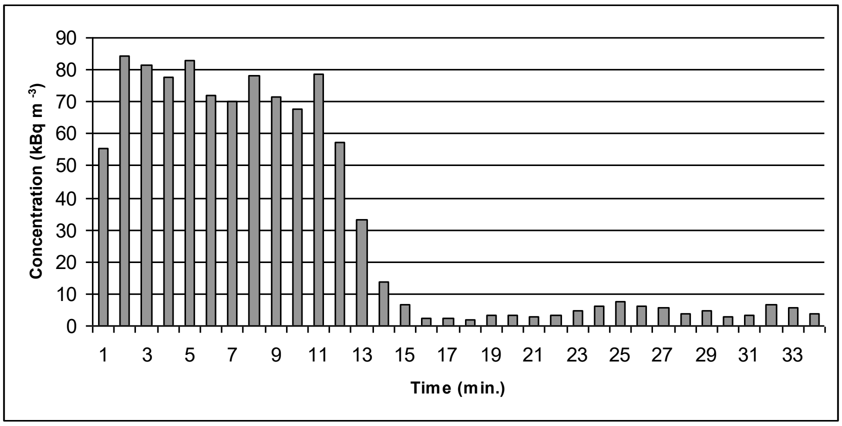

Figure 3. Representative results in the soil gas measured using the AlphaGuard monitor (from B12 district)

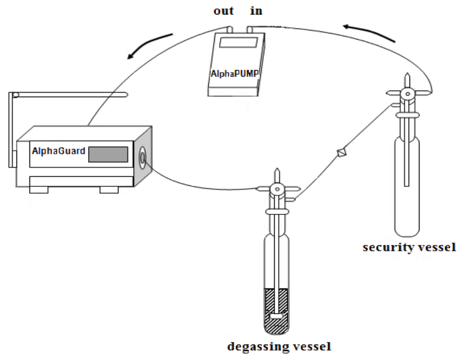

Figure 4. Schematic view of the AquaKIT measuring set-up in water

The outdoor gamma radiation levels were measured by a portable dose rate meter (Fluke Biomedical) (connected with a 489-55 model 1.5″ x1.5″ NaI(Tl) scintillation detector), as described by Akkaya et al. [29]. Sampling locations were chosen uncultivated, cultivated and near to populated areas to understand the amount of dose received by the population because of absorbed gamma dose rate in air.

4. Results

The results of the thoron and radon measurements in the soil gas with meteorological parameters, the radon measurements in the groundwaters and outdoor gamma dose rates are given in Table 1.

Table 1. Radon and thoron concentrations in the soil gas with meteorological parameters, radon concentrations in the groundwaters and outdoor gamma dose rates

			Concentration in the soil gas		Meteorological parameters		
Location (Code)	Gamma dose rate (nGy h^{-1})	Radon in the water (Bq l^{-1})	Radon (kBq m^{-3})	Thoron (kBq m^{-3})	Temp. (°C)	Pressure (mbar)	Humidity (%)
Armutçuk (B1)	80	52.35 ± 6.07	4.76 ± 0.28	34.78 ± 1.61	42	929	20
İsmetiye (B2)	80	37.85 ± 0.28	7.87 ± 0.66	63.23 ± 2.82	29	922	32
Danaçalı (B3)	79	11.75 ± 0.55	9.10 ± 0.36	80.33 ± 3.28	32	909	34
Kuşlar (B4)	198	24.15±1.08	0.71 ± 0.03	282.06 ± 22.86	30	898	29
Çeribaşı (B5)	94	22.86 ± 6.54	1.48 ± 0.27	14.86 ± 1.21	31	919	30
Durhasan (B6)	147	28.92 ± 0.20	5.39 ± 0.51	59.32 ± 2.78	37	925	32
Hacılar (B7)	75	22.78 ± 1.42	26.85 ± 0.94	71.23 ± 3.84	30	910	32
Aktaş (B8)	188	61.43 ± 0.55	36.25 ± 0.98	47.49 ± 2.56	37	924	25
Zaferiye (B9)	179	59.92 ± 0.02	27.58 ± 1.14	130.53 ± 5.49	30	889	34
Perçin (B10)	100	6.89 ± 1.11	2.96 ± 0.45	82.39 ± 3.75	29	919	28
Tekerler (B11)	128	7.04 ± 0.05	9.97 ± 0.34	67.15 ± 2.09	30	923	28
Kınık (B12)	72	7.14 ± 0.63	5.67 ± 0.42	67.50 ± 2.73	32	925	27
Karalar-1 (B13)	231	18.50 ± 0.56	9.69 ± 1.29	152.81 ± 12.96	27	918	47
Karalar-2 (B14)	**369**	NA	25.93 ± 4.32	**1462.50 ± 26.47**	25	906	51
Geynik (B15)	95	11.51 ± 0.08	0.54 ± 0.01	141.63 ± 11.20	28	917	44
Düğüncüler (B16)	75	12.78 ± 0.63	9.94 ± 0.28	34.68 ± 1.43	36	971	25
Balıoğlu (B17)	77	20.32 ± 3.13	NA	NA	---	---	---
Karağız (B18)	68	13.71 ± 0.86	NA	NA	---	---	---

NA: None Available

The radon and thoron concentrations in the soil gas were found to vary from 0.54 ± 0.01 kBq m^{-3} to 36.25 ± 0.98 kBq m^{-3} and from 14.86 ± 1.21 kBq m^{-3} to 1462.50 ± 26.47 kBq m^{-3}, respectively. In the region, the thoron concentrations in the soil gas were measured far higher than that of the radon. The measured radon concentrations in the groundwater samples ranged from 6.89 ± 1.11 to 61.43 ± 0.55 Bq l^{-1}. The measured outdoor gamma dose rates in the study region varied from 68 nGy h^{-1} to 369 nGy h^{-1}. On the basis of the results, contour maps of thoron and radon measurements in the soil gas, the radon measurements in the groundwaters and outdoor gamma dose levels are shown in Figure 5. Sampling locations are also demonstrated on these maps. Although a weak positive correlation (r=0.433) between outdoor gamma dose and radon concentrations in the soil gas, a good positive correlation (r=0.823) between outdoor gamma dose and thoron concentrations in the soil gas was observed.

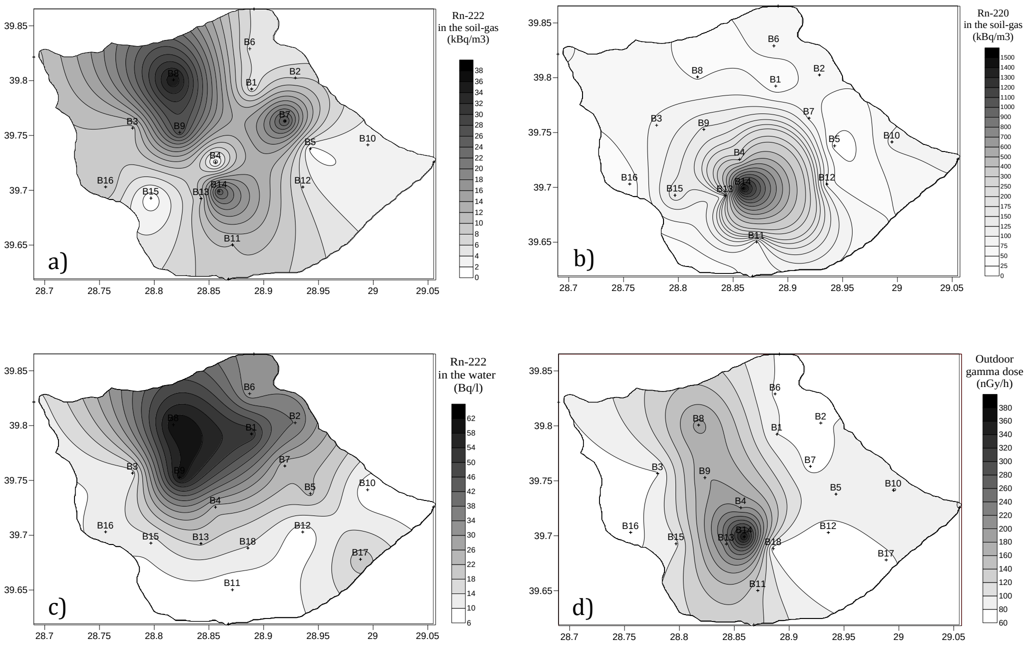

Figure 5. Contour maps of a) radon measurements in the soil gas, b) thoron measurements in the soil gas, c) radon measurements in the groundwaters, d) outdoor gamma dose rates

5. Discussion and Conclusions

Karalar-2 (B14) location has the highest outdoor gamma dose level (369 nGy h^{-1}). The same location has the highest thoron concentration in the soil gas (1.46 MBq m^{-3}). This measurement is the highest thoron concentration in the soil gas in the literature, as far as we know. There was no groundwater in this location. The origin of the thoron in the soil gas is entirely from the radium isotope, ^{224}Ra, a decay product of thorium series. The high thorium content in the soil influences the high thoron values. The monazite-rich areas with thorium in their chemical composition are known as sources of high thoron level [1]. ^{232}Th (thorium) activity concentration in the soil sample was found to be 235 Bq kg^{-1} by Akkaya [30] in this location. The other explanation of the thoron anomaly is that dry, permeable, sandy soil gives up its gases readily.

High thoron activities in soil gas may indicate a fast migration mechanism in the presence of a carrier gas (such as CO_2) as typically occurs along faults and fractured rocks, due to the short half-life of thoron [31]. Owing to their different half-lives, radon and thoron in the soil gas have different sources, i.e., relatively deep soil layers for radon, shallow soil layers for thoron [32]. The origin of the thoron in the atmosphere is almost entirely from diffusion from the top few centimeters of soil [33]. The other explanation is that thoron concentration in the soil gas is maximum in the areas with high surficial fracturing [7]. The mechanism that the thoron diffuses throughout the soil may be complex. Investigating the geological and geophysical characterization of the soil may be useful for predicting thoron emission, but little scientific study has been done so far. More detailed research is required in this location to explain the existence of very high thoron activities in the soil gas.

Radon and its decay products have been investigated for many years. However, little (less) information and attention is available about the thoron concentrations. In this research, according to effect of lithology of the region, it was carried out a survey of radioactivity, focusing on radon and thoron concentrations in the soil gas in the southern part of Bursa. The radon–thoron discriminative measurements are important especially in areas where high concentrations of radium or thorium are found. Additional measurements are required to understand better the levels of and effects of exposure to thoron and its decay products. This article also provides potential data for geological and geophysical applications, such as surficial fracturing investigations and prospecting for thorium deposits.

Acknowledgment

The author would like to thank Assoc. Prof. Dr. Ayşegül Kahraman and Prof. Dr. Gökay Kaynak for their valuable contributions.

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