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RADON CONCENTRATIONS AND GAMMA RADIATION ACTIVITY MEASUREMENTS OF MUĞLA, TURKEY

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Abstract. In the present study, the indoor radon activity concentrations in air were measured by using the LR-115 solid state nuclear track detectors in 25 dwellings (chosen as 9 old and 16 new) in Muğla, Turkey. The indoor radon activity concentration values for old dwellings vary from 160.37 to 367.54 Bq/m^3 and for new dwellings from 79.83 to 347.41 Bq/m^3. Moreover, the gamma-ray activity measurements of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs has been measured by using a HPGe detector for sand and sediment samples which were collected from Muğla. The activity concentration values for ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs vary from 5.6 to 72.6 Bq/kg, 2.26 to 38.03 Bq/kg, 79.54 to 867.48 Bq/kg and 0 to 1.42 Bq/kg, respectively. Most of the activity and effective dose values were within the limits of United Nations Scientific Committee on the Effects of Atomic Radiations (UNSCEAR) reports. In addition, a comparison between Muğla and other cities specified in the literature was also given.

Key words: natural radiation; activity concentration values; activities and effective dose values

1. INTRODUCTION

Whole living being on Earth exposed to natural and labored radiation. The natural background radiation mainly comes from cosmic radiation, terrestrial radiation and internal radiation [1]. The natural radioactive nuclides present in soil, rock, air and water. The labored radiation which is also known as human-made radiation arises because of variety of reasons such as medical, industry etc. Natural radiation is taken into body as gamma radiation originated from the Uranium, Thorium and Potassium series which are both known as terrestrial nuclides. The dose rate of gamma rays is related with the concentration of these natural radioactive nuclei.

Alpha radiation emanating from Radon gas is quickly taken through diffusion close to the atmosphere surface where radon is the product of natural Uranium decay. As it is known that inhalation of radon gas is life-threatening and causes the risk of lung cancer. Because many people spent much of their time inside the buildings, the measurement of indoor radon gas amount is important.

Radon insert the house from the soil and rock-based buildings and fill in to the house from the cracks at the bottom, the holes, the walls and from the installations [2]. Turkish Atomic Energy Authority (TAEA) [3] specified the limit levels for radon concentration as 400 Bq/m^3 for houses and 1000 Bq/m^3 for offices, in Turkey. The limit levels of European Union (EU) [4] for new houses are 200 Bq/m^3 and for old houses 400 Bq/m^3. The limit levels of International Commission on Radiological Protection (ICRP) [5] for houses are between 200 Bq/m^3 – 600 Bq/m^3 and for offices between 500 Bq/m^3 – 1500 Bq/m^3. Also Uranium, Thorium, Potassium activity values for UNSCEAR are in order of 35 Bq/kg, 30 Bq/kg and 400 Bq/kg respectively [6].

In this study, the samples obtained from 9 old and 16 new houses at the city center Muğla and the radon concentration measurements has been performed at the Istanbul University, Science Faculty, Nuclear Physics Radon Measurement Laboratory by using 100 LR-115 solid state nuclear track detectors. In addition to that, ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs gamma activity concentrations measured for 10 sand and 9 sediment samples which were taken from the seaside of Muğla, by using HPGe detector for the measurements. These results are analyzed in Istanbul University, Science Faculty, Nuclear Physics Gamma Spectroscopy Laboratory.

2. MATERIALS AND METHODS

2.1. STUDY AREA, SAMPLING AND INSTRUMENTATION

The study area Muğla is a province in the southwest of Turkey as shown in the detailed map (Fig. 1). The province of Muğla is between the latitude of 37°33' and longitude of 29°46' and most of its land is located in Aegean region and small part of it is in Mediterranean region. Muğla has two seasides to these regions. Muğla Province has a surface area of 12.794 km^2 and has a seashore of 1.500 km long which is the longest in Turkey. That is one of the reasons why Muğla has 9 harbor and sea border gates in total. This region has Mediterranean type climate and one of the biggest forestlands in Turkey. This area – beyond being just a touristic center – also has steam power plants and rich mineral stratums. Turkey's richest lignite stratum is in Yatağan, one of the districts of Muğla. Also, this region has many marble stratums and has an important role in marble industry.

In the first part of this work, measurement of radon concentration levels which obtained in the 25 dwellings at the center of Muğla, will be given. Sampling area was around 1.659 km^2 which are shown with squares in Fig. 1. LR-115 solid state nuclear track detectors which are sensitive to alpha particles have been used to measure the indoor radon concentrations. All measurements have been taken from the dwellings in different neighborhoods in Menteşe and Muğla districts. 100 LR-115 solid state nuclear track detectors placed to measure the radon concentration for

16 new (age around 20-year-old or less) and 9 old (age around 60 years or more) dwellings. These 25 houses selected spontaneously. For the radon gas measurement in a dwelling, LR-115 film type detectors were organized in certain shapes as 1.5 cm × 1.5 cm squares. Each one of them were placed at the bottom of a different transparent plastic cups and for every dwelling four LR-115 detectors were placed in. Each detector had a dedicated number, exact date of placing, exact coordinates of the dwellings and/or flats, temperature and humidity of the dwellings and/or flats. They both placed onto the surfaces of walls according to the height of the household and each detector system placed to the rooms where there are not any fresh air streams. These detectors were collected after 45 days. A dedicated chemical process was applied to the collected samples. This process performed by putting distilled water on 10-gram NaOH in a 250 ml beaker for each of the collected detectors and homogeneous 100 ml 10% NaOH solution obtained with the help of magnetic stirrer. Every four of these collected samples are carefully located into this chemical solution and put into 60°C water bath where the solutions with samples were hold for 95 minutes in hot water bath. After 95 minutes, detectors were taken out from hot solution to put in 200 ml distilled water and rinse approximately 20 minutes on the magnetic stirrer. Rinsed detectors dried in a 60°C hot oven for 30 minutes. Then, LR-115 film detectors were situated between lame/lamella system. The alpha particle tracks have been counted by using an optical microscope with appropriate software.

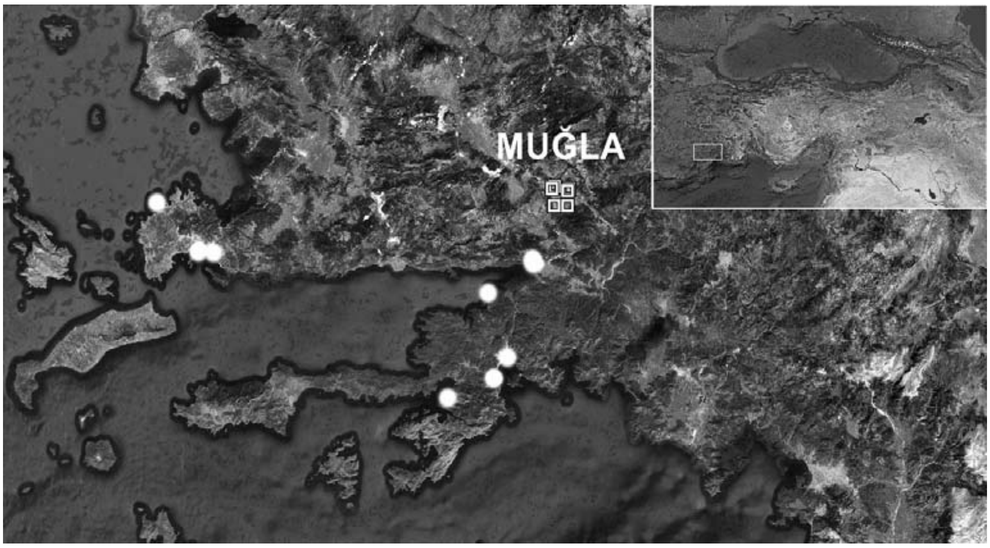

Fig. 1 – Geological map of the study area of Muğla. It can be seen from the inset of the map that Muğla belongs to the Aegean and the Mediterranean regions of Turkey [7]. Sampling areas can also be seen in the map; circles indicate the soil sampling areas while squares indicate the indoor Radon sampling in dwellings.

In the second part of this work, measurements of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs activity concentration levels and the annual effective dose values have been presented. These values have been calculated from samples which were collected randomly from 10 different seaside sands and 9 different sediment samples from the seaside of Muğla such as Bodrum, Ula and Marmaris. The area where samples taken given in Fig. 1 with white circles. The sand samples were taken from 20 cm depth of the sea. Each sample dried then sieved and finally, put in 500 ml Marinelli beaker cups. These prepared samples were reserved for 30 days to reach the radioactive equilibrium. The sand and sediment sample measurements were performed by using gamma spectroscopy system with p-type High Purity Germanium (HPGe) detector which has a %35 relative efficiency placed in the Nuclear Physics Research Laboratory at Istanbul University, Science Faculty. The energy resolutions (FWHM) of detector at 1.33 MeV for ^{60}Co and 122 keV for ^{57}Co were 1.85 keV and 935 eV, respectively. The analysis of spectra was carried out with Gamma Vision (ORTEC) software [8].

2.2. CALIBRATION

The calibration of LR-115 solid state track detectors performed in the radon concentration room in Health Physics Division in Çekmece Nuclear Research and Education Center (ÇNAEM), Istanbul, Turkey where the concentration level was 3.2 kBq/m^3.

The calibration of the detector done by measuring multi-nuclide standard source in Marinelli beaker container (AD-1275) which was purchased from Eckert & Ziegler Nuclitec GmbH [9]. The calibration measurement lasted 86400 seconds (24 hours) long and done in 19 December 2016. The energy and relative efficiency calibration of HPGe detector done over Cadmium-109, Cobalt-57, Cesium-137, Cobalt-60 and Yttrium-88 radioactive nuclides with the energy values of 88 keV, 122 keV, 661 keV, 1173 keV, 1333 keV and 1836 keV, respectively.

2.3. ACTIVITY MEASUREMENTS AND CALCULATIONS

Radon concentration (F) is equal to the track number per unit area (D_M) divided to calibration factor (C_F) and divided to the irradiated time of the detectors. By using the report of UNSCEAR-2000 [6], the annual effective equivalent dose calculations done by using a few equilibrium factor (H_E) between radon gas products. It has been foreseen that the average inhabitation in dwellings was 2000 hours per year. Equilibrium factor can vary between 0.2 to 0.8 depending on the living areas. Nevertheless, UNSCEAR chosen the equilibrium factor as 0.4 for all over the World. The equilibrium factor found as $H_E = 7.2 \times 10^{-3}$ (mSv/year)/(Bq/m^3).

The annual effective dose (AED, in mSv/year) using this equilibrium factor given below,

$$\text{AED} = F \times 7.2 \times 10^{-3} \frac{[\text{mSv/year}]}{[\text{Bq/m}^3]} \tag{1}$$

where F is the radon concentration (in Bq/m^3).

The ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs photopeak activity analysis has been performed for the spectrum given in Fig. 2. The activity calculation used for the samples as

$$A = \frac{N}{tm\gamma\varepsilon}[\text{Bq/kg}], \tag{2}$$

where N is the counting rate of the gamma-ray, t is the counting time in seconds which taken as 86400 seconds, m is the weight of the dried sample in kg which taken as 0.5 kg, γ is the probability of gamma decay and ε is the photopeak efficiency of the detector.

The absorbed gamma dose rate [nGy/h] equation is

$$D = (0.462 \times A_{\text{U}}) + (0.604 \times A_{\text{Th}}) + (0.0417 \times A_{\text{K}}), \tag{3}$$

where A_{U}, A_{Th} and A_{K} are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg, respectively.

The annual effective dose rate in μSv/year was estimated by the equation given below

$$E_{out} = D\left[\frac{\text{nGy}}{\text{h}}\right] \times 8760 \left[\frac{\text{h}}{\text{year}}\right] \times 0.2 \times 0.7 \times 10^{-3}. \tag{4}$$

Radium equivalent index (Ra$_{\text{eq}}$) is commonly used as radiological danger index in units of Bq/kg. This index can be calculated by the following equation;

$$\text{Ra}_{\text{eq}} = C_{\text{Ra}} + \frac{10}{7}C_{\text{Th}} + \frac{10}{130}C_{\text{K}}, \tag{5}$$

where C_{Ra}, C_{Th} and C_{K} are activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg. In this work this value is between 15.34 Bq/kg and 187.69 Bq/kg where the average value in the world is 89 Bq/kg. International Commission on Radiological

Protection (ICRP) determined the upper limit for the radiation dose from the construction materials as 15 mSv/y. The equation to calculate the radiation dose according to this upper limit is

$$H_{ex} = \frac{C_{Ra}}{740} + \frac{C_{Th}}{520} + \frac{C_K}{9620} \le 1 \tag{6}$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively. In this work this value is between 0.02 Bq/kg and 0.16 Bq/kg.

Also, inherent danger index (H_{in}) gives the amount of the hazard of radon and its products with short lifetimes which were exposed to the respiratory organs. The equation for this is the following:

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \le 1. \tag{7}$$

In this work this value varies between 0.06 Bq/kg and 0.56 Bq/kg.

3. RESULTS AND DISCUSSION

The indoor radon concentrations can be seen in Table 1 and Table 2 both indicates the radon concentration and annual effective dose values for old and new dwellings, respectively.

Table 1

Radon concentrations and annual effective doses for old dwellings in Muğla

Sampling Points	Radon Activity [Bq/m^3]	Annual Effective dose [mSv/year]	Temperature [°C]	Humidity [%RH]	Layer
Menteşe Orhaniye Neighb. 1	367.01	2.64	25.1	%60	Basement
Menteşe Düğerek Neighb. 1	167.83	1.21	30.4	%25	Basement
Menteşe Düğerek Neighb. 2	202.05	1.45	31.6	%26	Basement
Menteşe Düğerek Neighb. 3	171.14	1.23	31	%24	Basement
Menteşe Düğerek Neighb. 4	210.71	1.51	31	%27	Basement
Menteşe Düğerek Neighb. 5	213.71	1.54	31.1	%32	Basement
Menteşe Düğerek Neighb. 6	212.56	1.53	32.1	%23	Basement
Menteşe Düğerek Neighb. 7	354.3	2.55	32.1	%30	Basement
Menteşe Düğerek Neighb. 8	170.7	1.22	31.1	%29	Basement

Table 2

Radon concentrations and annual effective doses for new dwellings in Muğla

Sampling Points	Annual Effective dose [mSv/year]	Temperature [°C]	Humidity [%RH]	Layer
Menteşe Emir Beyazıt Neighb. 1	1.16	29.7	%38	Basement
Menteşe Düğerek Neighb. 1	2.19	27.3	%51	Basement
Menteşe Orhaniye Neighb. 1	0.97	34.2	%36	First floor
Menteşe Orhaniye Neighb. 2	1.08	30.7	%36	First floor
Menteşe Kötekli Neighb. 1	1.13	28.3	%43	First floor
Menteşe Emir Beyazıt Neighb. 2	0.96	31.3	%35	First floor
Menteşe Düğerek Neighb. 2	1.16	27	%47	First floor
Menteşe Orhaniye Neighb. 3	0.84	24	%59	First floor
Menteşe Emir Beyazıt Neighb. 3	1.14	28.6	%41	First floor
Menteşe Emir Beyazıt Neighb. 4	0.63	31	%33	Second floor
Menteşe Orhaniye Neighb. 4	0.82	32	%35	Second floor
Menteşe Orhaniye Neighb. 5	1.12	31.2	%36	Second floor
Menteşe Kötekli Neighb. 2	0.91	31	%55	Second floor
Menteşe Düğerek Neighb. 3	0.94	28.1	%52	Second floor
Menteşe Emir Beyazıt Neighb. 5	0.82	31.8	%35	Third floor

One can see that:

- For old dwellings, the radon concentration values (F) change between 167.83 Bq/m^3 – 367.01 Bq/m^3 and for these dwellings the average concentration value has been found as 230.01 Bq/m^3 where for new dwellings the radon concentration values change between 87.6 Bq/m^3 – 304.94 Bq/m^3 and for these dwellings the average concentration value has been found as 144.84 Bq/m^3. Due to International Atomic Energy Agency Basis Security Standards (IAEA-BSS), the radon concentration level is between 200 Bq/m^3 – 600 Bq/m^3 and this value is 400 Bq/m^3 for Turkey which is determined by Turkish Atomic Energy Authority (TAEA) [3]. So that the average values are compatible with TAEA standards for both old and new dwellings.
- The exposed annual effective dose rate which has been calculated with Eq. 1, in 9 old dwellings is between 1.21 mSv/year – 2.64 mSv/year and the mean annual effective dose is 1.65 mSv/year which can be seen in detail in Table 1. In Table 2, the details can be found for exposed annual effective dose for 16 new dwellings and the dose rate changes between 0.63 mSv/year – 2.19 mSv/year while the mean value is 1.04 mSv/year.
- Since all the old dwellings only have one floor all the measurements taken from the basement floor. These one-floored old dwellings manufacturing materials mainly contain stone, sand and adobe. These materials are the main reason why in these dwellings the radon concentration levels are higher. Consequently, the annual effective dose exposed by the inhabitants are higher (see Table 1).

- For new dwellings, measurements are taken from different floors so that the radon concentration alteration varies according to different floor levels. Main expectancy is to see lower radon concentration level at higher floors but due to the lack of ventilation there are some contradictory values (see Table 2).
- As shown in Fig. 2, for the new dwellings the radon concentration values decrease from the basement level to upper floors as expected. Based on the measurements and due to the comparison of the values of TAEA and UNSCEAR, these results are within the limit values but for old dwellings the radon concentration and annual effective dose rates are higher than expected. Especially the radon concentration and the annual effective dose rates in the old dwellings at Muğla/Menteşe/Orhaniye Neighborhood 1 and Muğla/Menteşe/Düğerek Neighborhood 7 are in the limit values but in higher level. One of the reasons for that is the construction material of these houses are mainly stone but also the other reason for these results is that the region is well-known in marble industry, so it is possible that mainly or partly marble can be used in the construction of these houses. Radon concentrations for old dwellings given in Fig. 3.

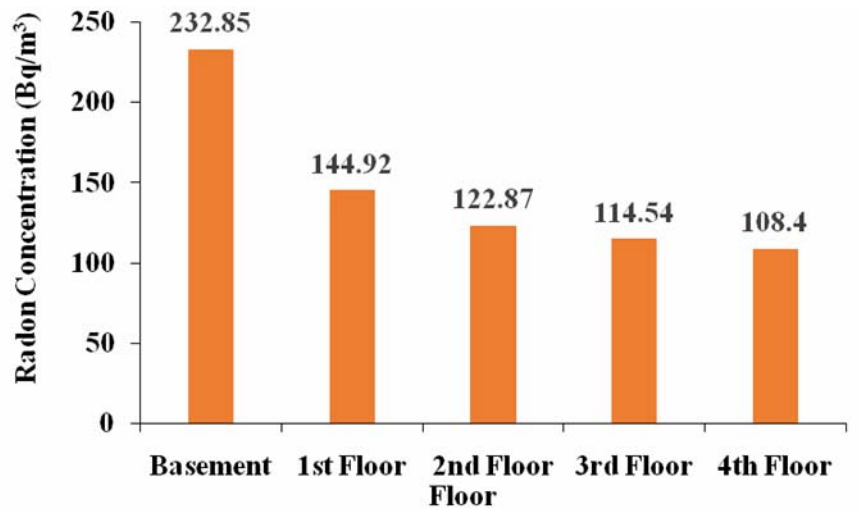

Fig. 2 – Radon concentrations for new dwellings according to different floors as basement, 1st, 2nd, 3rd and 4th. Radon Concentration values are higher at lower levels compared to higher levels and compatible with TAEA standards as expected.

In the second part of this work, for collected soil and sediment samples from the seaside of Muğla, the activity concentration values and the effective dose of the sampling points (9 sediments and 10 sand) were given in Table 3 and Table 4, respectively.

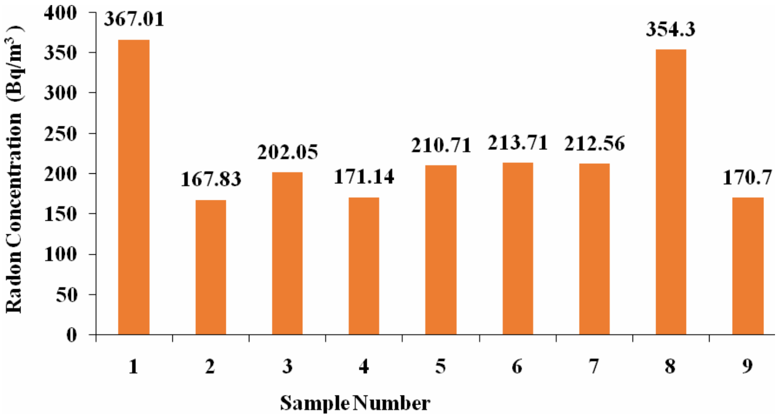

Fig. 3 – Radon concentrations for old dwellings according to sample number which indicates the old dwellings order. Radon concentration values differs according to the construction material and the age of the dwellings.

Table 3

The activity concentrations in the sampling points

Sample Number	Sampling Points	U-238 Activity [Bq/kg]	Th-232 Activity [Bq/kg]	K-40 Activity [Bq/kg]	Cs-137 Activity [Bq/kg]
1	Marmaris / Turgutköy	12.84 ± 0.23	10.21 ± 0.18	373.08 ± 3.2	1.42 ± 0.05
2	Marmaris / Karacaköy 1	9.13 ± 0.21	2.46 ± 0.1	90.69 ± 1.76	0.04 ± 0.01
3	Marmaris / Karacaköy 2 (Sediment 53 cm)	5.6 ± 0.18	2.53 ± 0.1	79.54 ± 1.68	0.03 ± 0.01
4	Marmaris / Karacaköy 3 (Sediment 178 cm)	10.2 ± 0.22	3.07 ± 0.1	84.31 ± 1.71	< MDA
5	Marmaris / Center	7.49 ± 0.19	2.91 ± 0.1	258.73 ± 2.71	0.81 ± 0.04
6	Marmaris /İçmeler Neighb. 1	12.62 ± 0.23	4.19 ± 0.12	370.79 ± 3.19	0.41 ± 0.03
7	Marmaris /İçmeler Neighb. 2 (Sediment 65 cm)	6.42 ± 0.19	3.34 ± 0.11	210.17 ± 2.47	0.44 ± 0.03
8	Marmaris /İçmeler Neighb. 3	7.6 ± 0.2	2.26 ± 0.09	145.82 ± 2.12	0.18 ± 0.02
9	Bodrum / Yalıkavak Neighb. 1	56.54 ± 0.43	29.36 ± 0.29	658.09 ± 4.18	0.08 ± 0.01
10	Bodrum / Yalıkavak Neighb. 2 (Sediment 65 cm)	72.56 ± 0.48	38.03 ± 0.33	788.9 ± 4.55	< MDA
11	Bodrum / Gümbet Neighb. 1	18.21 ± 0.27	8.85 ± 0.16	766.13 ± 4.49	0.07 ± 0.01
12	Bodrum / Gümbet Neighb. 2 (Sediment 45 cm)	30.12 ± 0.33	14.31 ± 0.21	675.94 ± 4.23	0.38 ± 0.03
13	Bodrum / Gümbet Neighb. 3	18.14 ± 0.26	7.11 ± 0.15	705.92 ± 4.32	< MDA
14	Bodrum / Gümbet Neighb. 4 (Sediment 45 cm)	32.62 ± 0.34	13.64 ± 0.2	867.48 ± 4.77	0.05 ± 0.01
15	Bodrum / Center	16.27 ± 0.25	6.86 ± 0.15	517.66 ± 3.73	0.09 ± 0.01
16	Ula / Akyaka Neighb. 1 (Sediment 55 cm)	10.92 ± 0.22	3.98 ± 0.12	117.31 ± 1.94	< MDA
17	Ula / Akyaka Neighb. 2 (Fresh Water Source)	13.21 ± 0.23	4.86 ± 0.13	119.94 ± 1.96	0.07 ± 0.01
18	Ula / Akyaka Neighb. 3	8.66 ± 0.2	3.72 ± 0.11	103.78 ± 1.85	0.02 ± 0.01

Table 4

The effective dose in the sampling points

Sample Number	Sampling Points	Absorbed dose [nGy/h]	Annual Effective dose [µSv/y]	H_{index}		Ra_{eq} [Bq/kg]
				H_{ex}	H_{in}	
1	Marmaris /Turgutköy	27.66	33.92	0.08	0.19	56.17
2	Marmaris /Karacaköy 1	9.49	11.63	0.03	0.08	19.63
3	Marmaris /Karacaköy 2 (Sediment 53 cm)	7.43	9.11	0.02	0.06	15.34
4	Marmaris /Karacaköy 3 (Sediment 178 cm)	10.08	12.37	0.03	0.08	21.08
5	Marmaris /Center	16.01	19.63	0.04	0.11	31.57
6	Marmaris /İçmeler Neighb.1	23.82	29.22	0.06	0.16	47.16
7	Marmaris /İçmeler Neighb. 2 (Sediment 65 cm)	13.75	16.86	0.04	0.09	27.38
8	Marmaris /İçmeler Neighb. 3	10.96	13.44	0.03	0.08	22.06
9	Bodrum /Yalıkavak Neighb. 1	71.30	87.44	0.20	0.56	149.2
10	Bodrum /Yalıkavak Neighb. 2 (Sediment 65 cm)	89.39	109.62	0.25	0.70	187.69
11	Bodrum /Gümbet Neighb. 1	45.70	56.05	0.12	0.29	89.86
12	Bodrum /Gümbet Neighb. 2 (Sediment 45 cm)	50.75	62.23	0.14	0.36	102.63
13	Bodrum /Gümbet Neighb. 3	42.11	51.65	0.11	0.27	82.66
14	Bodrum /Gümbet Neighb. 4 (Sediment 45 cm)	59.48	72.95	0.16	0.41	118.92
15	Bodrum /Center	33.24	40.77	0.09	0.22	65.94
16	Ula /Akyaka Neighb. 1 (Sediment 55 cm)	12.34	15.14	0.03	0.1	25.64
17	Ula /Akyaka Neighb. 2 (Estuary of Azmak)	14.04	17.21	0.04	0.12	29.4
18	Ula /Akyaka Neighb. 3	10.57	12.97	0.03	0.08	21.97
19	Ula /Akyaka Neighb. 4 (Sediment 50 cm)	12.0	14.72	0.03	0.09	25.01

One can see that:

- The Uranium, Thorium and Potassium activity values for UNSCEAR are in order of 35 Bq/kg, 30 Bq/kg and 400 Bq/kg respectively [6]. Annual effective dose and absorbed dose for each sample number given in Fig. 4. Mainly in Bodrum the doses are higher than other sampling points.
- Cesium activity value is in order of 0.21 Bq/kg which is lower compare to other regions of Turkey as can be seen from Table 5.
- For the report of UNSCEAR, the annual effective dose limit in the sand is 66 µSv/year [6]. Table 5 shows the comparison of radiation in samples taken from Muğla, Turkey with the published results from different countries and the results which were given in the UNSCEAR reports.

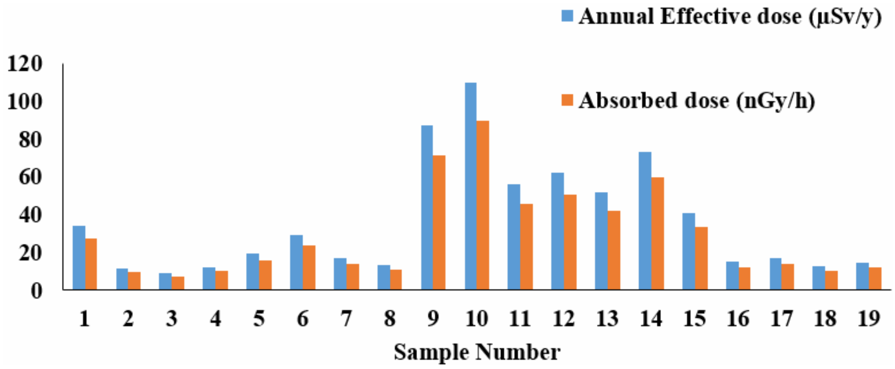

Fig. 4 – Annual effective dose and absorbed dose values according to sample number.

Table 5

The comparison of radiation in samples of Muğla. Turkey with the published results from different countries and with the UNSCEAR reports

Sampling Location	U-238 Activity [Bq/kg]	Th-232 Activity [Bq/kg]	K-40 Activity (Bq/kg)	Cs-137 Activity (Bq/kg)	References
Corbu Beach, Romania	12.20	8.50	233.00	1.30	**[13]**
India	56.74	87.42	143.04	–	**[14]**
Saudi coastline	11.42	22.48	641.08	3.47	**[15]**
Red Sea, Egypt	22.70	12.40	930.00	–	**[18]**
Vadu Beach, Romania	6.50	5.00	38.00	0.70	**[13]**
Thailand	12.70	23.00	654.30	–	**[20]**
Ulcinj City Beach, Serbia	7.40	9.00	192.00	0.40	**[23]**
Kastamonu, Turkey	32.93	27.17	431.43	8.02	**[10]**
Şanlıurfa, Turkey	21.00	25.00	299.00	9.00	**[11]**
Batman, Turkey	35.00	25.00	274.00	12.00	**[12]**
Kayseri, Turkey	35.51	37.27	429.66	11.53	**[16]**
Samsun, Turkey	31.00	22.00	341.00	16.00	**[17]**
Ezine region, Turkey	–	532.00	1160.80	–	**[19]**
Rize, Turkey	50.00	42.00	643.00	85.00	**[21]**
Kocaeli, Turkey	8.90	8.90	219.40	–	**[22]**
UNSCEAR	35.00	30.00	400.00	–	**[6]**
Muğla, Turkey	18.87	8.75	371.09	0.21	**Present study**

4. CONCLUSIONS

The measurements compared with the UNSCEAR values and some values are under and some are above the safety limits. Radon concentrations for new dwellings are in the limits and for old dwellings the concentrations are higher but in the limits. The Uranium, Thorium, Potassium and Cesium activity concentration values, imposed gamma dose and annual effective dose values are mainly below the safety limits except Bodrum region. One reason may be that this area is on marble stratum and other reason may be that this is an area of very rocky terrain. Depending on these features, it is concluded that differences in activity concentrations are related to rocky structure of the region.

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