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Measurement of Indoor Seasonal and Regional Radon (222Rn) Gas Activity in Çanakkale (Turkey)

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Abstract
Radon gas, which undergoes radioactive decay, can cause damage to the lung tissue and lung cancer over time in indoor environments where it is inhaled. Radon gas radioactivity concentrations were measured using CR-39 passive solid state nuclear track detectors (SSNTD) in the basement and ground floor simultaneously in summer and winter periods in 17 dwellings in Çanakkale Center and Kepez regions (Turkey). Accordingly, an average of 163.67 Bq.m^{-3} in basements in summer, 63.26 Bq.m^{-3} in ground floors in summer, 148.73 Bq.m^{-3} in basements in winter, and 77.57 Bq.m^{-3} in ground floors in winter. In addition, annual effective dose equivalent (AEDE) values and excess lifetime cancer risk (ELCR) parameters were calculated using radon activity concentrations. Accordingly, the basement and mean AEDE values in the summer period were found to be 4.52 µSv.y^{-1} and 1.59 µSv.y^{-1}, respectively. In winter, it was found as 3.75 µSv.y^{-1} and 1.95 µSv.y^{-1}.

1. Introduction

There is natural radioactivity of earth's crust or cosmic origin, and artificial radioactivity resulting from nuclear tests and accidents. Regionally, radioactivity can be found in different concentrations. Since ionizing radiation negatively affects human health in proportion to the amount of exposure, it is important to determine the radiation level in living areas and to take possible precautions.

There are four basic decay chains in nature and the most dominant source of naturally occurring ionizing radiation is radon gas (^{222}Rn). Radon, the only gas intermediate product of the ^{238}U natural decay chain found in soils and rocks, is a chemically stable, colorless and odorless gas. Radon gas taken into the body through respiration turns into ^{210}Pb, a relatively long-lived and toxic radioisotope, by emitting ionizing radiations with a rapid decay mechanism. Because of these properties, radon gas is the second most important cause of lung cancer after smoking [1]. In 2018, it is estimated that there were close to 2 million new cancer cases and 1.7 million deaths in the world. In Turkey, an average of 23,000 men and 4,500 women are diagnosed with lung cancer annually. Studies show that there is a link between indoor radon gas exposure and lung cancer, although radon gas levels are relatively low in residential buildings [2]. Radon gas is found in relatively low concentrations (~15 Bqm^{-3}) due to atmospheric changes outside the buildings [3]. The reason for the direct or indirect concentration of radon gas indoor is the ^{226}Ra isotope in the soil [4]. Radon gas in the ambient can create high concentrations due to cracks and gaps in buildings, water used at home or building materials [5]-[8]. Indoor radon concentration varies depending on the type of soil in which the houses are located, the rocks around or under the building, the construction materials, the water source coming to the house, the temperature and pressure differences, the use of natural gas or other fossil fuels, and the living habits of the people.

Determination of radon levels indoor where people spend a long time is very important for human health. For this reason, indoor radon gas levels are investigated in different environments. Many studies have been reported with active or passive methods in different countries for the detection of radon gas in

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dwellings (Table 1). When the results obtained are compared with the previous studies in the world and in Turkey, it is revealed that there are quite compatible results, especially with randomly selected samples from the world. In fact, it shows very close values with Sweden, which is generally accepted as high radon concentration. Considering the climatic conditions, it can be accepted that the low ventilation in the winter season in countries such as Sweden, Germany, Pennsylvania (USA), and Tehran (Iran) increases the value. In addition, the low or variable values in countries such as Kuwait and Colombia can be attributed to climatic conditions and more ventilation due to the hot climate. In addition to this, examples of different countries should also be discussed in detail in terms of different living cultures, habits, and differences in house types.

When it is considered for Turkey, this time, assuming that there are similar living habits and considering the climatic conditions as the determinant, cities such as Içel and Kahramanmaraş are located in the region with Mediterranean climate characteristics, and the summer period lasts for a long time. On the other hand, cities such as Edirne, Istanbul, Bitlis, Kırıkkale, Sivas, Adapazarı, Bayburt are settlements where the cold period is longer or equal to the warm period. However, there are no significant differences between these cities. Very high values were encountered in an old settlement in Ahlat (Bitlis), and therefore the average values were considerably higher. Most of the examples given from both Turkey and the world include the radon concentration values in the bedroom or living room. In the study conducted in Çanakkale within the scope of this study, values were obtained from both normal living areas and basement floors where life partially continues. The fact that the values especially in the basement floors are high is one of the most important differences. However, although measurements were taken in the basement floors in Edirne, for example, values as high as those in Çanakkale could not be reached.

Since nuclear trace detectors are cheap and easy to use, there are many studies using CR-39 nuclear trace detectors among these studies. In addition to these advantages, it also has disadvantages such as not being able to receive instantaneous data due to being a passive detector, not knowing the existence of possible background traces at the beginning and changing the count result according to the user while counting the traces. However, manufacturers have minimized this margin of error with products such as etching baths and robotic assisted automatic counting systems.

In this study, it was aimed to determine the radon gas levels in the basement and ground floors of the same buildings in different ground conditions, in winter and summer periods, in Çanakkale center and Kepez regions, using CR-39 passive nuclear trace detectors.

2. Material and Method

In the frame of this study, CR-39 passive SSNTD (Solid State Nuclear Tracking Detectors) were used to determine regional and seasonal changes in radon gas concentration in 17 dwellings in Çanakkale.

2.1. Sampling Area

The dwellings where the detector will be placed were selected from Çanakkale center and Kepez regions depending on the soil content structure (Figure 1). In seasonal total, 34 detectors were placed in selected dwellings. Two detectors are installed in each house, one in the basement and the other on the ground floor. The rooms where the detectors were placed were mostly chosen as the bedroom or living room where the households spent more time.

The color separation seen on the map represents different ground conditions. Çanakkale is a coastal city and mainly consists of marine alluvium. Sand and silt are predominantly found in the alluvium. 12 detectors are placed in the built dwellings on the alluvium (Al). 5 detectors are located within the structures on the Alçıtepe (Aç) formation, which has sandstone, marl and mudstone characteristics. As can be seen from this information, the effect of Çanakkale soils, which are mostly dominated by granular soil units, on radon concentration was observed in this study. Granular units, due to their high permeability, allow radon gas to be easily discharged from underground to the surface. In this case, it is expected that there will be more radon gas emission to the indoor environment.

Table 1. Some indoor radon studies in literature.

Location	^{222}Rn Activity (Bq.m^{-3})	Specifications	Reference
Germany	70 mean	44,629 dwellings For 40 years period SSNTD	[9]
USA, Pennsylvania	181, 178, 161, 143 autumn, winter, spring, summer respectively mean values	1,808,294 dwellings For 40 years period, seasonal SSNTD	[3]
Columbia, Menizales	50 max. 85 geometric mean	202 houses; Related to location area, floor level, wall and floor material and number of people living in the house, SSNTD	[10]
Kuwait	7±1 – 404±21 at school 13±1 - 595±30 at basement of residential dwellings	150 sites at school classrooms and basement of residential dwellings	[11]
İran, Tehran	31 – 460.2 average 104	30 dwellings	[12]
Sweden	151 mean	60,809 houses, for 5 years period SSNTD	[13]
Turkey, İçel	Winter 13-59 range, 44 mean Summer 22-159 range, 23 mean	100 houses, bedrooms and living rooms, Seasonal, SSNTD	[14]
Turkey, Edirne	49.2	88 houses at basement, SSNTD	[15]
Turkey, Çanakkale (Ezine)	9-300 range, 67.9 mean	58 dwellings, summer season, SSNTD	[16]
Turkey, Bayburt	17-125 range, 56 mean	44 houses, SSNTD	[17]
Turkey, Sivas	Winter mean 89 Summer mean 98	98 houses, seasonal SSNTD	[18]
Turkey, Adapazarı	59.9 at houses, 57.1 at schools 61.7 mean	31 schools and 50 dwellings SSNTD	[19]
Turkey, Kırıkkale	Winter 17-484 range, 86.94 mean Summer 14-288 range, 63.27 mean	150 houses, seasonal SSNTD	[20]
Turkey, Bitlis (Ahlat)	10-2031 range 259.86 mean	50 houses related to construction material SSNTD	[21]
Turkey, İstanbul	17.4 ground floor, 8.5 first floor	16 dwellings in a university campus, Related to floor level, Active AlphaGuard detector	[22]
Turkey, Kahramanmaraş	Winter 8.52-53.12 range, 67.30 mean Summer 4.74-22.79 range, 52.25 mean	12 dwellings in a university campus, seasonal Active Rad7 detector	[23]
Turkey, Çanakkale	Basement winter 148.73 summer 163.67 Ground floor winter 77.57 summer 63.26	17 buildings, basement and ground floors, seasonal SSNTD	Present Study

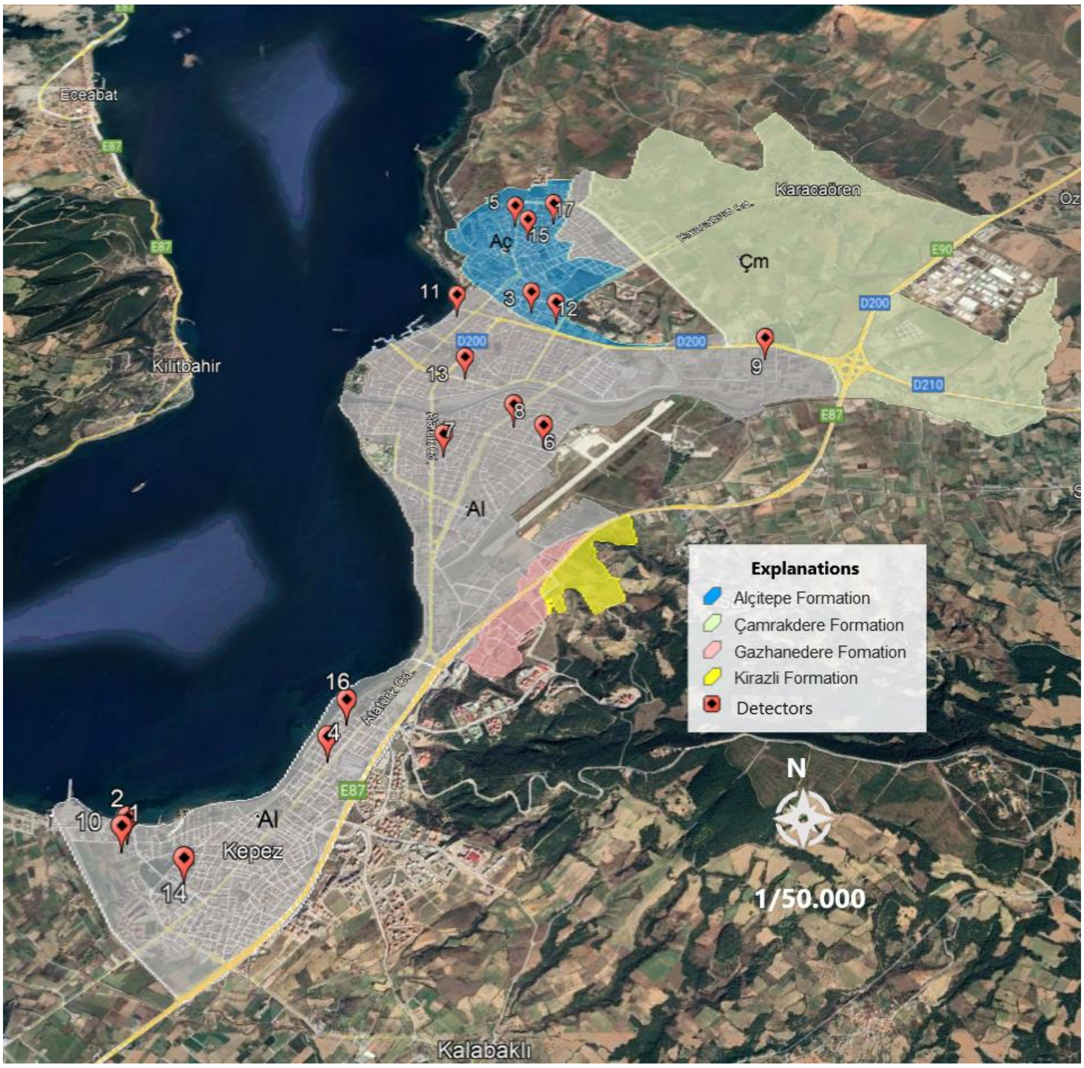


Figure 1. Distribution of CR-39 detectors in the study area. Al: Alluvium, Aç: Alçıtepe formation (mudstone, marl, siltstone, sandstone, calcarenite and locally thin conglomerate unit), Çm: Çamrakdere formation (mudstone-claystone, siltstone, sandstone, conglomerate and calcareous unit)

2.2. Measurements of Procedures

Detectors were placed in the selected dwellings for approximately 100-125 days between the months of June-September and October-January, since the detectors used had to be kept in the environment for a minimum of 80 days due to the calibration determined by the manufacturer. At the end of this period, the detectors collected were brought to the laboratory and the chemical etching process was started. 10mm×10mm and 1mm thick detectors, whose IDs are engraved as dot-code on them and placed in the diffusion chamber (which has 10 μm airgaps for effective diffusion of radon atoms (in the range of 10^{-4} μm) [24], are placed on 12 slides.

After chemical etching (6M NaOH, 9 hours, 90°C), counts were made with a (×40) zoom optical microscope and RadoSYS automatic counting system with a 3-megapixel camera. The trace densities were determined by counting the traces in the images taken from nine different surfaces on each detector for five times (Figure 2). Counts were made using the software RadoMeter RSV8 TA/8 v4.52 available for the Linux operating system. Then, with the help of the equation including the calibration coefficient, exposure time and trace densities given by the detector manufacturer, the radon gas activity concentrations were obtained in Bqm^{-3} (Eq. 1) [24].

$$C_{Rn}(Bq.m^{-3}) = 1000 \times TD \times CF/t \qquad (1)$$

Where C_{Rn} is the radon gas activity value, TD is the trace density obtained from the count, CF is the calibration coefficient of the CR-39 detectors (41.44 h.kBq.[m^3(track.mm^{-2})]$^{-1}$) and t is the exposure time in the dwellings [21].

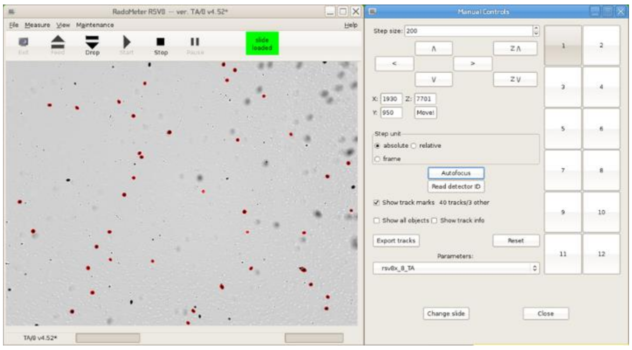


Figure 2. Determination of trace densities by counting the traces 5 times in the images taken from 9 different surfaces on each detector.

2.3. Calculation of Radiological Effects

In order to determine the possible harmful effects of radon gas, parameters such as the amount of exposure and cancer risk are calculated by using the radon activity concentration values. The following expression is used when calculating the Annual Effective Dose Equivalent (AEDE).

$$AEDE(\mu Sv.y^{-1}) = C_{Rn} \times EF \times T \times DCF \qquad (2)$$

Where CRn is radon activity concentration value (Bq.m^{-3}), EF is Equilibrium Factor of radon and its products for buildings (0.4) [25], T is exposure time to indoor radon gas (7000 h.y^{-1}) and DCF is dose conversion factor (9×10-6 mSv (Bq.h.m^{-3})$^{-1}$) [25].

Using the annual effective radon dose exposed, the Excess Lifetime Cancer Risk (ELCR) value originating from radon gas is calculated with the help of the equation below.

$$ELCR = AEDE \times ALT \times RF \qquad (3)$$

Where ALT is average lifetime (70 years), and RF is fatal risk factor per Sv (0.05) [26]. The ELCR value reveals a relative relationship to the probability of developing cancer disease in relation to AEDE [27],[28].

3. Results and Discussion

When the indoor radon gas concentration measurement results covering Çanakkale center and Kepez Town are evaluated, two different average values emerge. The seasonal average activity value in the basement floors was 163.67 Bq.m^{-3} (Table 2) in summer and 148.73 Bq.m^{-3}, (Table 3) in winter. However, abnormal values emerged at 2 points (dwelling ID numbers: 11 and 15) within these values in basement floor measurements (Figure 3). Radon gas activity observed in basements is higher than in other floors, since radon gas first enters the basements in the buildings and reaches the upper floors after creating a certain concentration there. In addition, the fact that ventilation possibilities or periods are weak compared to other floors also contributes to this difference.

If these values are not taken into account, the summer average is 81.03 Bq.m^{-3} and the winter average is 83.61 Bq.m^{-3}, as expected. On the other hand, there are 5 dwellings (dwelling ID numbers: 8, 10, 11, 13, 15) exceeding 100 Bq.m^{-3} in the basement floors during the summer period. There are 4 dwellings (dwelling ID numbers: 10, 11, 13, 15) exceeding 100 Bq.m^{-3} in the basement floors during the winter period. On the ground floors, there are 1 dwelling in the summer period and 3 dwellings in the winter period, with a value of more than 100 Bq.m^{-3} (dwelling ID numbers: 6 and 8, 10, respectively).

The seasonal average activity value on the ground floors was found to be 63.63 Bq.m^{-3} in summer and 77.57 Bq.m^{-3} in winter (Figure 4). Radon gas concentration measurements were made simultaneously in the ground and basement floors. Despite this, the average activity values of the basement floors were found to be higher than those of the ground floors both in the summer and winter periods. When evaluated specifically for the dwelling, the activity value measured in the winter period is higher than that measured in the summer period in 52.94% of the basement floors. In 70.59% of the dwellings on the ground floor, the activity value measured in the winter period was found to be higher than in the summer period.

Table 2. Radon activity concentrations in summer season.

Summer Season								
	Basement				Ground Floor			
Dwelling ID	Rn Activity (Bq.m^{-3})	Error	AEDE (μSv.y^{-1})	ELCR (%)	Rn Activity (Bq.m^{-3})	Error	AEDE (μSv.y^{-1})	ELCR (%)
1	43.58	1.58	1.10	0.004	82.99	1.85	2.09	0.007
2	56.03	1.63	1.41	0.005	76.52	1.11	1.93	0.007
3	44.74	1.51	1.13	0.004	27.63	3.44	0.70	0.002
4	76.49	0.38	1.93	0.007	48.62	1.07	1.23	0.004
5	80.99	2.98	2.04	0.007	58.22	2.37	1.47	0.005
6	20.32	1.02	0.51	0.002	156.62	4.08	3.95	0.014
7	55.19	1.28	1.39	0.005	59.05	1.64	1.49	0.005
8	118.55	0.19	2.99	0.010	76.00	0.43	1.92	0.007
9	81.11	0.38	2.04	0.007	43.00	3.49	1.08	0.004
10	292.12	0.30	7.36	0.026	84.49	0.86	2.13	0.007
11	760.57	0.57	19.17	0.067	41.66	2.61	1.05	0.004
12	52.28	0.36	1.32	0.005	53.72	0.64	1.35	0.005
13	131.10	0.14	3.30	0.012	50.68	1.12	1.28	0.004
14	87.60	1.20	2.21	0.008	76.83	1.60	1.94	0.007
15	806.34	0.58	20.32	0.071	55.15	1.57	1.39	0.005
16	36.61	2.50	0.92	0.003	38.68	0.45	0.97	0.003
17	38.72	3.48	0.98	0.003	45.52	0.76	1.15	0.004
Min.	20.32		0.51	0.002	27.63		0.70	0.002
Max.	806.34		20.32	0.071	156.52		3.95	0.014
Mean	163.67		4.12	0.014	63.26		1.59	0.006
TAEK	400				400			

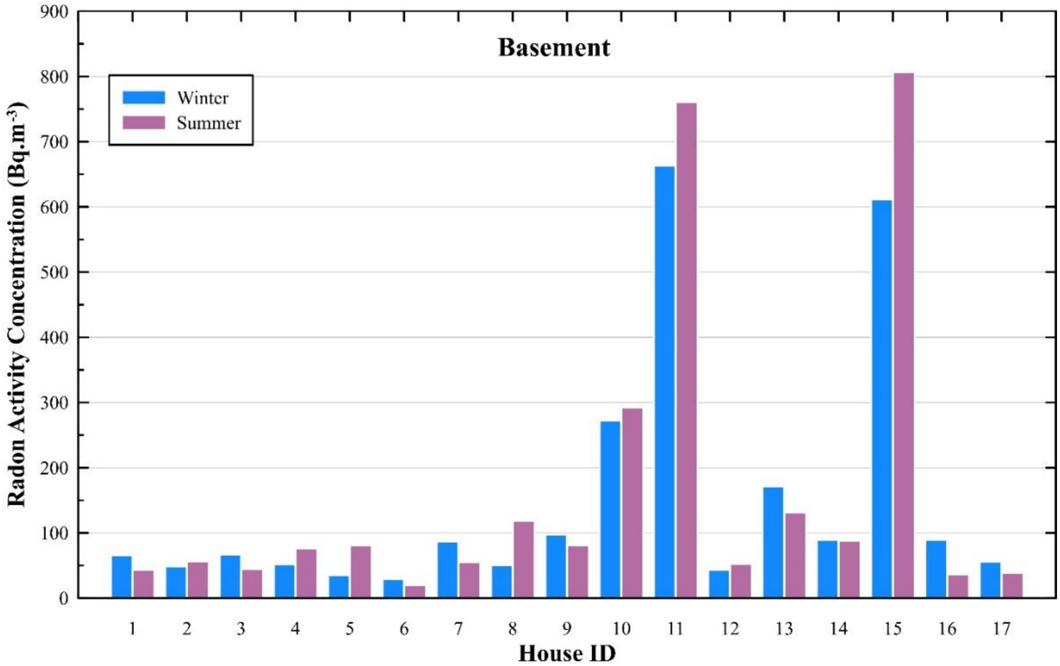


Figure 3. Seasonal radon measurements in basement.

Table 3. Radon activity concentrations related to winter season

Winter Season								
Basement					Ground Floor			
Dwelling ID	Rn Activity ($Bq.m^{-3}$)	Error	AEDE ($\mu Sv.y^{-1}$)	ELCR (%)	Rn Activity ($Bq.m^{-3}$)	Error	AEDE ($\mu Sv.y^{-1}$)	ELCR (%)
1	65.68	1.92	1.66	0.006	83.28	1.26	2.10	0.007
2	48.66	2.09	1.23	0.004	81.17	0.98	2.05	0.007
3	66.69	2.51	1.68	0.006	23.06	2.10	0.58	0.002
4	52.03	1.46	1.31	0.005	70.78	1.44	1.78	0.006
5	35.09	12.35	0.88	0.003	36.33	1.33	0.92	0.003
6	29.13	1.13	0.73	0.003	46.34	1.34	1.17	0.004
7	86.49	1.20	2.18	0.008	39.36	2.11	0.99	0.003
8	50.55	2.32	1.27	0.004	143.61	1.64	3.62	0.013
9	97.39	3.16	2.45	0.009	53.75	2.79	1.35	0.005
10	272.27	0.32	6.86	0.024	207.66	0.73	5.23	0.018
11	662.93	0.41	16.71	0.058	62.94	0.91	1.59	0.006
12	43.65	2.45	1.10	0.004	45.12	0.77	1.14	0.004
13	171.52	3.31	4.32	0.015	84.47	2.96	2.13	0.007
14	89.53	1.83	2.26	0.008	95.72	0.81	2.41	0.008
15	611.36	0.55	15.41	0.054	98.95	4.29	2.49	0.009
16	89.68	1.02	2.26	0.008	94.82	1.27	2.39	0.008
17	55.78	2.41	1.41	0.005	51.36	1.71	1.29	0.005
Min.	29.13		0.73	0.003	23.06		0.58	0.002
Max.	662.93		16.71	0.058	207.66		5.23	0.018
Mean	148.73		3.75	0.013	77.57		1.95	0.007
TAEK	400		1.00		400		1.00	

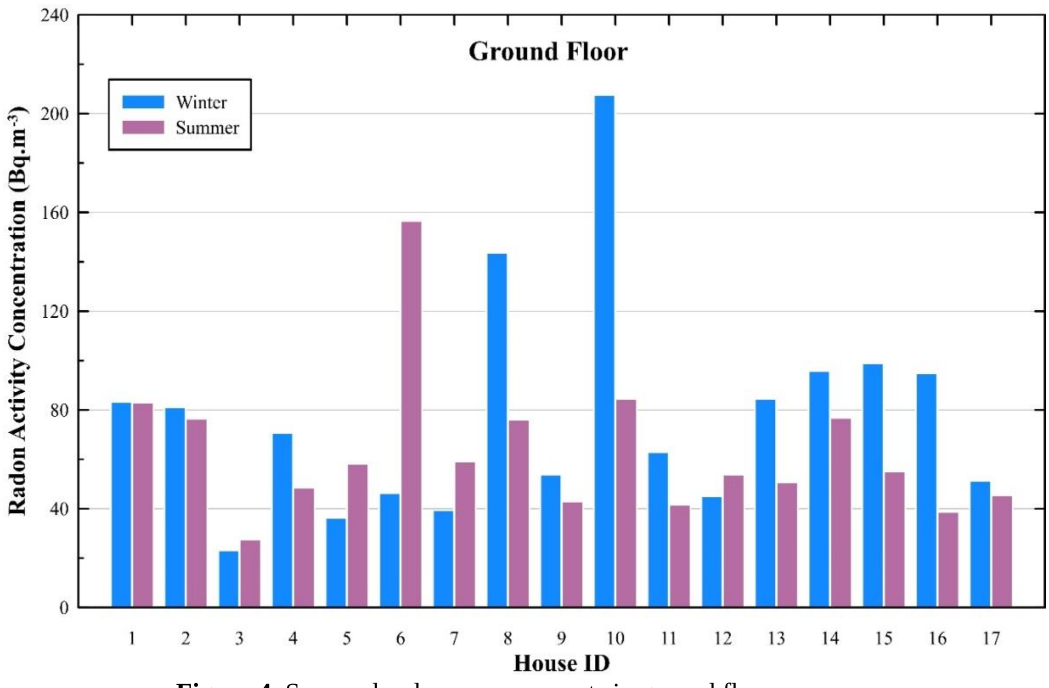


Figure 4. Seasonal radon measurements in ground floors.

It has been determined that 58.82% of the basement floors of the same dwellings are higher than the values measured on the ground floor during the summer period. In the winter period, this value was determined as 47.06%. The seasonal comparison of basements and ground floors is given in Figure 5 for summer and Figure 6 for winter seasons.

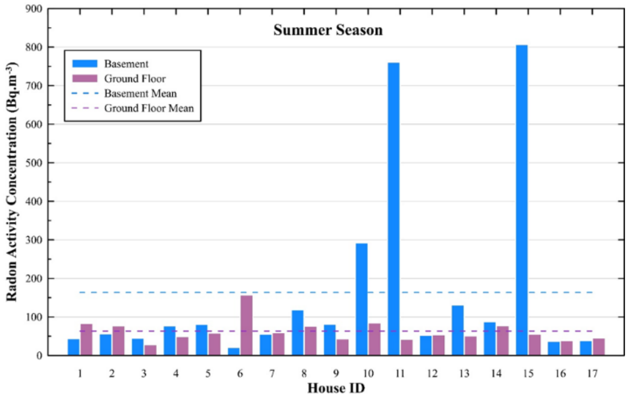


Figure 5. Comparison of basements and ground floors for the summer season.

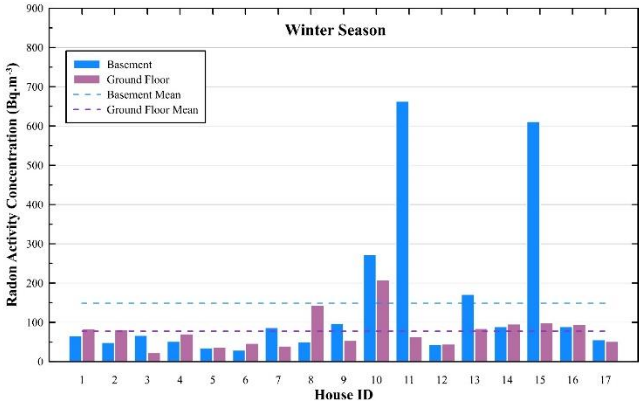
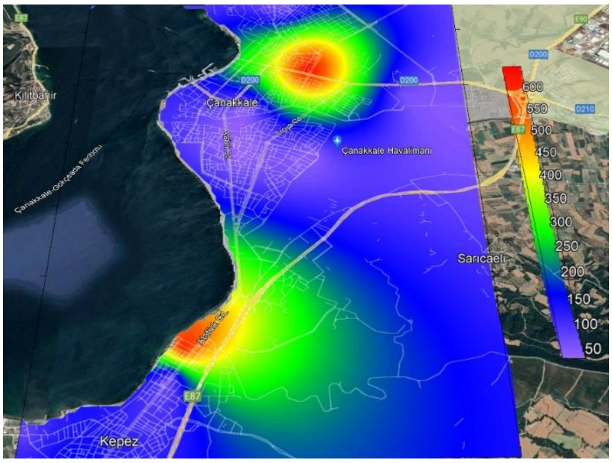


Figure 6. Comparison of basements and ground floors for the winter season.

The mean annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) were calculated and are given in Table 2 for the summer period and Table 3 for the winter period. The mean annual effective dose equivalent and the excess lifetime cancer risk were determined by calculating the summer and winter averages of radon activity. AEDE was between 0.51-20.32 μSv.y^{-1} in basements for the summer period, with a mean value of 4.12 μSv.y^{-1}. The ground floors ranged from 0.70-3.95 μSv.y^{-1} and the mean value was 1.59 μSv.y^{-1}. For the winter period, basements ranged from 0.73-16.71 μSv.year^{-1} and the mean value was 3.75 μSv.y^{-1}. The ground floors ranged from 0.58-5.23 μSv.y^{-1} and the mean value was 1.95 μSv.y^{-1}. Although these average values remain within the range of the action level (3–10 μSv.y^{-1}) recommended by the ICRP [29] in basements, they are mainly caused by abnormal values. In addition, it remained below the action level (3–10 μSv.y^{-1}) recommended by the ICRP [29] for ground floors. The lifetime cancer risk (ELCR) value represents the percentage of cancer risk, or the probability of having cancer in every 100,000 people. The ELCR was on average in basements and ground floors 14×10^{-3} and 6×10^{-3} percent for the summer period respectively. Similarly, it was on average in basements and ground floors 13×10^{-3} and 7×10^{-3} percent for the winter period respectively. Most of the selected buildings have the characteristics of the lower floor and upper floor of the same residence, which are defined as duplexes. For this reason, life in these residences continues in the form of basement and ground floor at the same time.

(a)



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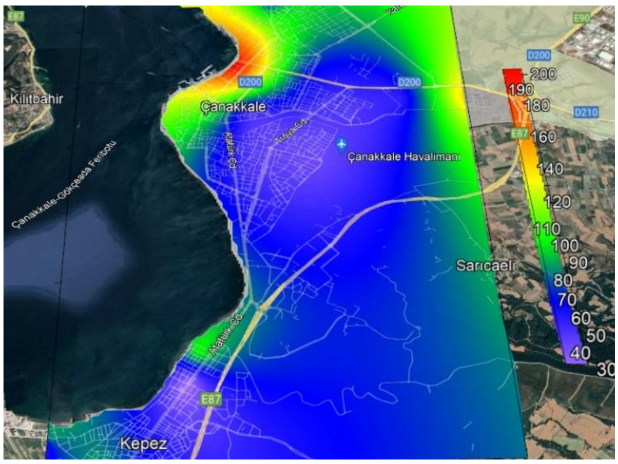
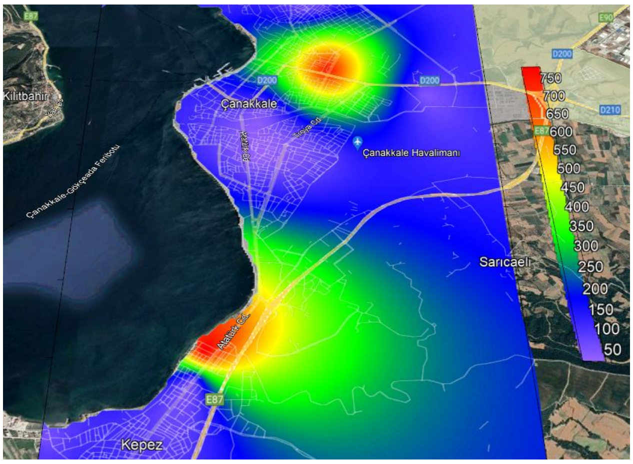
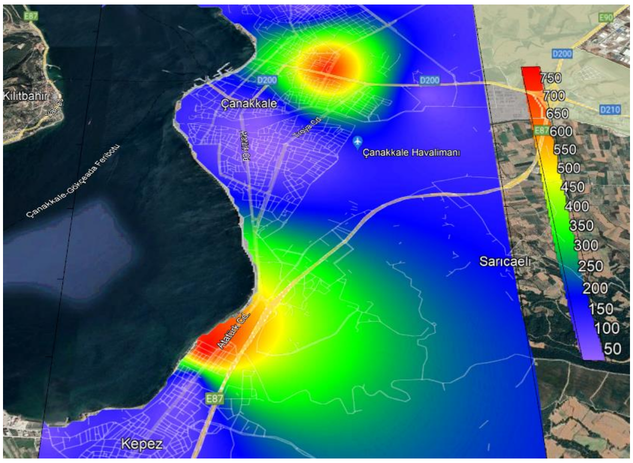




(c)



(d)

Figure 7. (**a**) Basement floor distribution in the winter period, (**b**) Ground floor distribution in the winter period, (**c**) Basement floor distribution in the summer period, (**d**) Ground floor distribution in the summer period.

4. Conclusion

In this study, radon gas levels, covering 17 buildings in Central settlement and Kepez region of Çanakkale in Northwest of Turkey, were measured simultaneously in both the basements and the ground floors. When the obtained activity concentration results were evaluated in general, a general average result of 113.31 Bq.m^{-3} was obtained. The general radon concentration value obtained because of the studies carried out in 5500 houses in Turkey, regardless of season or floor, was determined as 82.66 Bq.m^{-3} [30]. In a study conducted in Ezine, Çanakkale [16], measurements were made in 58 houses and an average value of 67.90 Bq.m^{-3} was obtained. When the results obtained in this study are evaluated from this point of view, activity concentration values above the average values obtained both in Çanakkale and throughout Turkey were obtained. The reason for these high average activity values is the high values obtained in both seasons in the two basement floors 11 and 15. When the general average is calculated by excluding the values of these two houses, a value of 75.53 Bq.m^{-3} is obtained. Observations were made comparing seasonal, spatial, domestic behavior conditions and soil conditions. Accordingly, no dramatic difference was observed in the radon gas levels in the basements or ground floors. Since there is less ventilation in the basement floors, there are increased values in radon gas levels compared to the floors above the basement. The values in 2 basements with no ventilation were measured much higher than the accepted value (between 600-800 Bq.m^{-3}). Radon gas levels observed in dwellings with an older construction year, especially in old residential areas of the city, are higher. On the other hand, although there is no significant difference in value depending on soil conditions, the radon gas values observed in the rock environment are higher than those in alluvial conditions. In some ground floors with insufficient ventilation, the value exceeded 100 Bq. The mean annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) is at a level that does not require any action in the absence of abnormal values. However, in basements with abnormal values, conditions have arisen that require taking precautions. All these results reveal that ventilation conditions are the main reason affecting indoor natural radon gas values unless there is a very specific source. Even if the ventilation conditions are respected, the presence of 4-5 times more radon gas in the indoor breathing air should be considered as a risk of life in the indoor ambient. Annual effective dose equivalent (AEDE) showed high values in rarely visited areas where Rn concentrations accumulate due to improper ventilation. The average radon concentration measured in the basements of the houses was significant for the annual effective dose for the residents. Although the soil conditions do not show a significant change for the study area, radon gas leaks from the cracks and shows a higher concentration, especially in the areas where rocks are dominant. On the other hand, since it is easily exposed on sandy soils, its concentration in indoor environments also decreases.

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Contributions of the authors

All contributions to this study belong to the authors.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics

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