Check for updates

Original Paper

Indoor and Built Environment

Indoor and Built Environment
2017, Vol. 26(3) 327–336
© The Author(s) 2015
Reprints and permissions:
sagepub.co.uk/
journalsPermissions.nav
DOI: 10.1177/1420326X15606508
journals.sagepub.com/home/ibe
SAGE

Mapping of indoor radon survey and dose estimations in health centres in Turkey

Nevzat Damla[1], Ayhan Kara[2], Eyüp Tel[3] and Cafer M. Yesilkanat[4]

Abstract

Radon and its short-lived daughter products, leading to lung cancer, are the most significant contribution to the exposure of man to ionizing radiation from natural sources. Therefore, the present study aimed to assess indoor radon measurements in 39 rooms of 15 health centres in Osmaniye city, Turkey using CR-39 solid-state nuclear track detectors based on radon dosimeters. Indoor radon concentrations were found to change from 8 to 108 $Bq{\cdot}m^{-3}$. The associated radiological parameters such as the annual effective dose and excess lifetime cancer risk were computed for staff/patient in the rooms surveyed. The mean annual effective dose and excess lifetime cancer risk values were estimated to be 0.29 mSv and 1.02×10^{-3}, respectively. The annual computed effective doses are lower than the suggested action level (3–10 $mSv{\cdot}y^{-1}$). Also, with ordinary Kriging method, by using R programing language and quantum geographic information system, indoor radon concentration, annual effective dose, and excess lifetime cancer risk interpolated values were recorded and mapped. The findings obtained in the current study concerning radon levels and their variations will provide baseline values for future research surveys.

Keywords
Indoor radon, health centre, annual effective dose, excess lifetime cancer risk

Accepted: 25 August 2015

Introduction

Radon, a colourless, odourless, tasteless, and chemically inert gas, whose half-life is 3.82 d, is a naturally occurring radioactive gas stemming from the radioactive decay of ^{226}Ra, the fifth daughter of ^{238}U. Radon and its progeny are the most important contribution to human exposure to ionizing radiation from natural sources. This contribution represents about half of the annual effective dose (AED) equivalent to natural radiation attributable to the world mean.[1–6]

This remarkable level of radon radiology hints the necessity to take it under control in the residences or workplaces since people spend a lot of time in these buildings. Therefore, the measurement and restriction of radon concentration in buildings are vital.[7] Radon is one of the most threatening carcinogen elements, and it is also known as the second most important of lung cancer agent in all the cases reported.[1,8,9] It is difficult to feel its presence with the human sensory organs. The accumulation of Radon and its products in the respiratory tract can be fatal; moreover, long duration exposure to radon can pave the way for lung cancer.[1,10] When the natural radiation-related deaths are considered, radon gets first place. According to UNSCEAR value,[1] the main problem is that its gas

[1]Department of Physics, Batman University, Batman, Turkey
[2]Department of Nuclear Energy Engineering, Sinop University, Sinop, Turkey
[3]Department of Physics, Osmaniye Korkut Ata University, Osmaniye, Turkey
[4]Department of Physics, Artvin Curh University, Artvin, Turkey

Corresponding author:
Nevzat Damla, Department of Physics, Batman University, Batman 72060, Turkey.
Email: nevzat.damla@batman.edu.tr

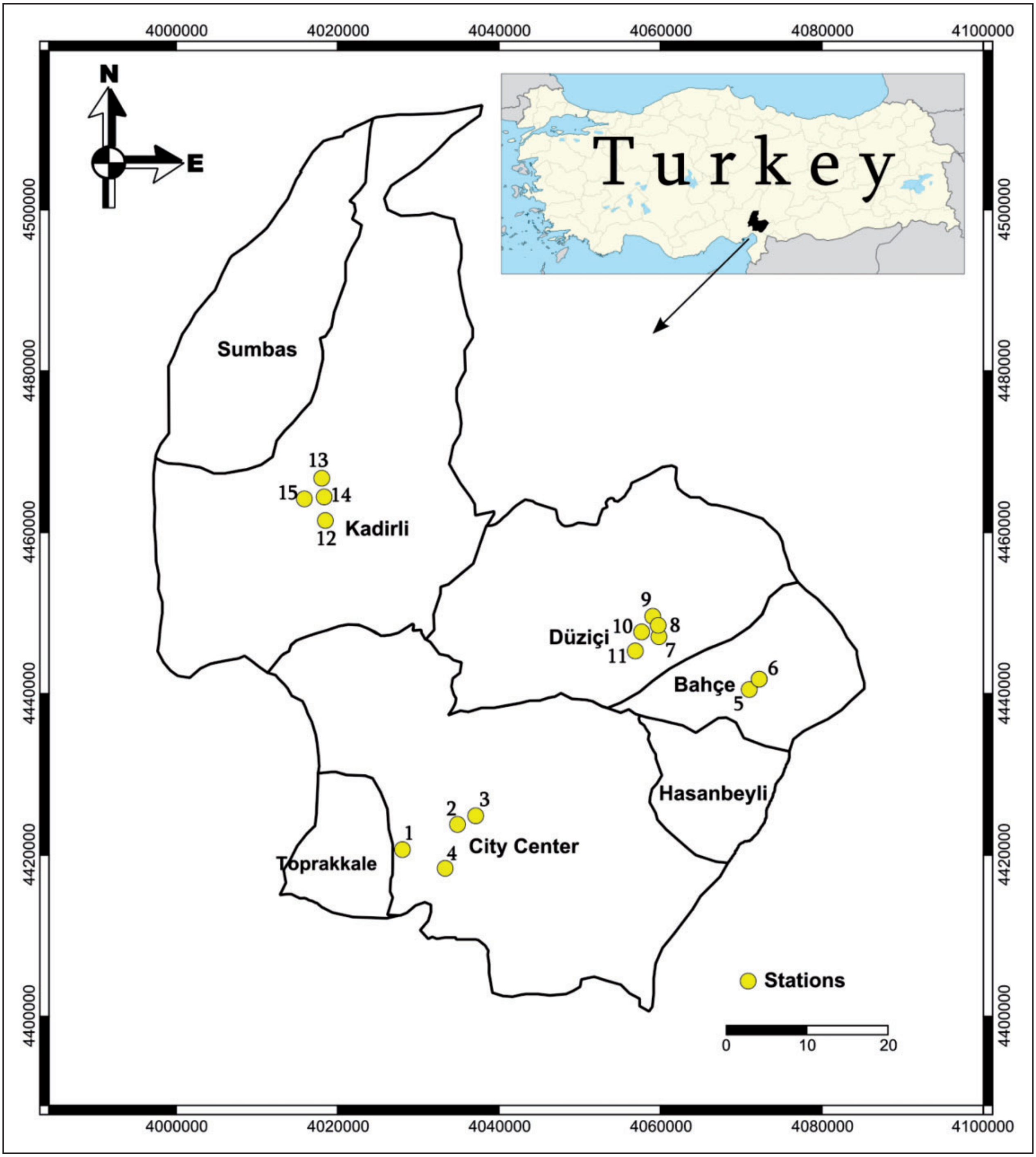

Figure 1. Location of sampling areas.

can be easily inhaled. Because it is associated with lung cancer, the study of indoor radon measurements is very important, and even these studies contribute to create awareness.

As far as known, few researches on radon in hospitals have been conducted.[11–16] The objective of this study is to examine indoor radon concentrations in 15 health facilities in Osmaniye province and its districts (Bahçe, Düziçi, and Kadirli) in Turkey and to estimate the AEDs and excess lifetime cancer risks (ELCR) depending on the concentration of radon exposure on health staff. In this study, based on the obtained measurements, interpolated estimations were created for the area. It is anticipated that this study will provide the baseline values for studies that will be conducted in future.

Table 1. The coordinates and numbers of detector placed in health centre buildings.

Location	Health centre	Number of detector	Coordinates
City centre	Public hospital – physical medicine service	5	37° 03′03.81 ″N, 36° 11′04.13 ″E
	Oral and dental health centre	4	37° 04′27.46 ″N, 36° 14′40.90 ″E
	Maternity hospital	3	37° 04′56.38 ″N, 36° 15′57.57 ″E
	Family health centre – 15	2	37° 02′19.83 ″N, 36° 13′41.51 ″E
Bahçe	Public hospital	3	37° 11′49.17 ″N, 36° 34′21.80 ″E
	Family health centre	2	37° 12′02.21 ″N, 36° 34′38.10 ″E
Düziçi	Public hospital	3	37° 14′40.10 ″N, 36° 27′40.92 ″E
	Public hospital out building	1	37° 14′40.10 ″N, 36° 27′40.92 ″E
	Family health centre – 1	2	37° 15′17.27 ″N, 36° 27′14.65 ″E
	Family health centre – 2	2	37° 14′34.07 ″N, 36° 26′08.48 ″E
	Family health centre – 3	2	37° 13′47.50 ″N, 36° 26′41.24 ″E
Kadirli	Public hospital	4	37° 22′00.09 ″N, 36° 05′41.08 ″E
	Family health centre – 1	2	37° 22′40.97 ″N, 36° 06′01.57 ″E
	Family health centre – 2	2	37° 22′14.96 ″N, 36° 06′03.94 ″E
	Family health centre – 4	2	37° 21′52.11 ″N, 36° 04′32.05 ″E

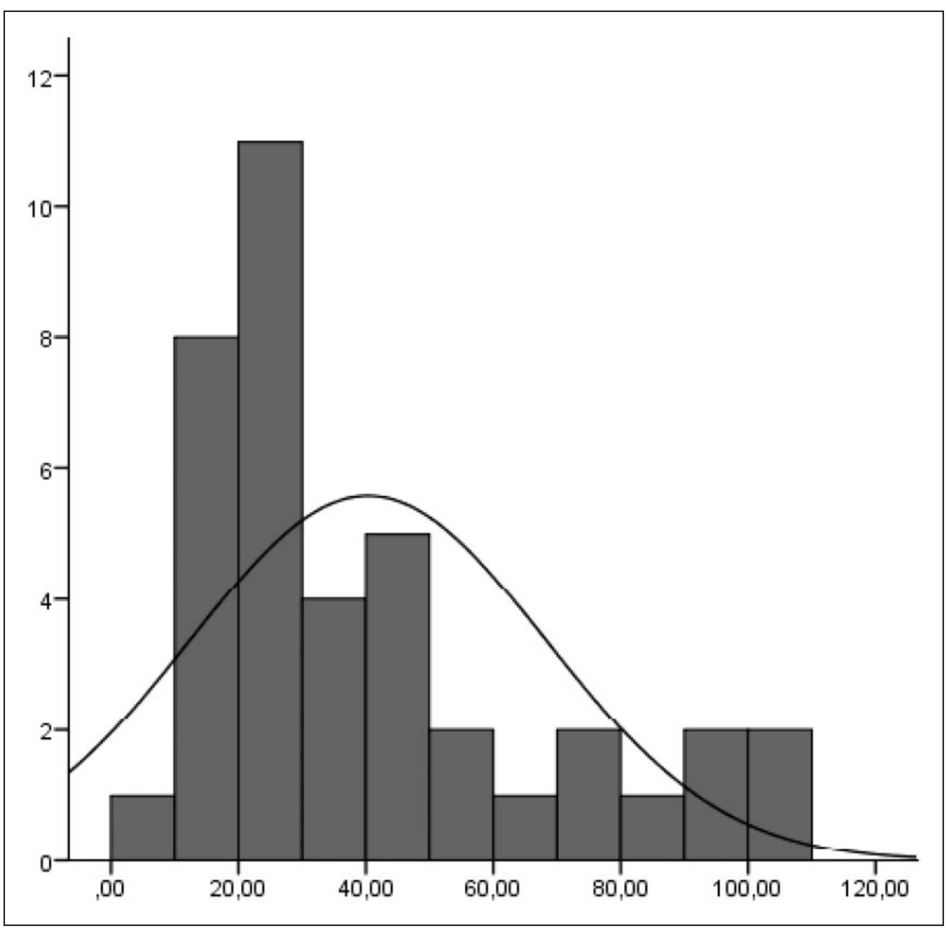

Figure 2. Frequency distribution of indoor radon concentration.

Table 2. Statistical analysis of indoor radon concentrations.

Variables	^{222}Rn ($Bq\cdot m^{-3}$)
Mean	40
Std. error of mean	4
Median	28
Mode	15
Std. deviation	28
Variance	777
Geometric mean	33
Skewness	1.2
Kurtosis	0.4
Range	100
Minimum	8
Maximum	108
Percentiles	
25	19
50	29
75	54

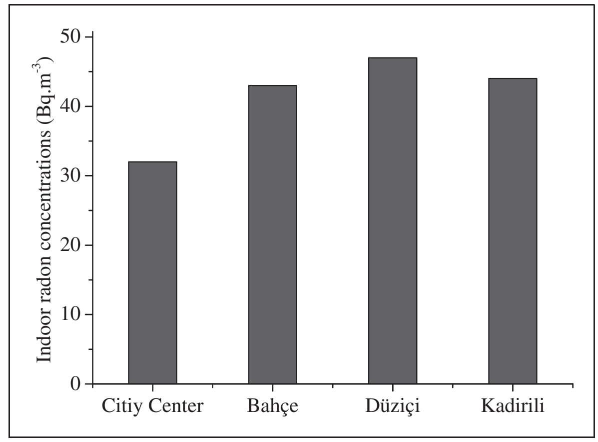

Figure 3. Indoor radon concentration in districts.

Experimental studies

Sampling area

The province of Osmaniye is located in the eastern Mediterranean region of Turkey, and it is situated between 35° 52′–36° 42′ E longitudes and 36° 57′–37° 45′ N latitudes. The population of the city is approximately 506,807. Mediterranean climate dominates over the city. Summers in Osmaniye are quite hot and dry, whereas winters are cool and very wet. The city is divided into seven districts (Figure 1).

Indoor radon concentration measurements

In order to perform this study, 39 dosimeters involving CR-39 solid-state nuclear track detectors (SSNTDs), long-term monitoring of radon concentrations, have been placed in rooms on different floors of 15 hospitals located in Osmaniye province, Turkey. Figure 1 shows the locations of Osmaniye health centres surveyed. The distribution of detectors placed in the health centres and the coordinates of these centres are given in Table 1.

Since the number of detectors was limited, they were not placed in all the health centres in the three districts of Sumbas, Toprakkale, and Hasanbeyli. The placed dosimeters remained in the health centre buildings for a period of 90 days. All dosimeters were placed at head height on the cupboards in the rooms on various floors of each health centres. Prior to the survey, information was given to every health centre management about the radon issue in working environments and explaining the aim and schedule of measurements to be conducted. Then, each hospital was visited, and by means of joint work with the management, representative measuring sites were selected, submitting priority to the rooms on the ground floors since they were visited by many people, and also to the other rooms on upper floors but fewer in numbers.

After 90-day exposure, the CR-39 detectors were gathered and enclosed within an aluminized plastic bag for total isolation until they reached the laboratory. The CR-39 detectors $10 \times 10 \times 1$ mm^3 in size were devised and embedded in a plastic container of 4 mm in height, letting radon diffuse. The containers were closed with a plastic cap so as to avoid dust accumulation on the detector foils. Measurements of the detectors were conducted by Radosys 2000 system (77 Electronica, Budapest, Hungary). The system is a complete set allocation to the radon concentration measurement. It comprises a Radometer-automated microscopic image analyzer with a control computer, track analysis software, Radopot CR-39 plastic alpha-track detectors, and the RadoBath etching unit. Calibration of the system was carried out by means of RadoCal calibration package.[17,18] After the irradiation, etching process was carried out in 25% NaOH solution at 90°C for 4 h for CR-39 films. The reading of the number of alpha particle tracks per unit area on the CR-39 detector was automatically carried out by utilizing a digital image-processing system (Radosys).[19]

Results and discussions

Indoor radon measurements were surveyed in 39 rooms of 15 major hospitals in Osmaniye city, Turkey by using a CR-39 SSNTDs based on radon dosimeters.

Table 3. Radiological parameters in health centre buildings.

Location	Health Centre		AED (mSv)	ELCR ($\times 10^{-3}$)
City centre	Public hospital – physical medicine service	Minimum	0.11	0.38
		Maximum	0.22	0.78
		Mean	0.16	0.56
	Oral and dental health centre	Minimum	0.11	0.38
		Maximum	0.17	0.60
		Mean	0.14	0.48
	Maternity hospital	Minimum	0.12	0.43
		Maximum	0.19	0.66
		Mean	0.15	0.53
	Family health centre – 15	Minimum	0.65	2.27
		Maximum	0.77	2.70
		Mean	0.71	2.49
Bahçe	Public hospital	Minimum	0.12	0.43
		Maximum	0.15	0.53
		Mean	0.22	0.78
	Family health centre	Minimum	0.35	1.21
		Maximum	0.54	1.89
		Mean	0.45	1.55
Düziçi	Public hospital	Minimum	0.13	0.45
		Maximum	0.33	1.16
		Mean	0.22	0.76
	Public hospital out building	Minimum	0.11	0.38
		Maximum	0.11	0.38
		Mean	0.11	0.38
	Family health centre – 1	Minimum	0.29	1.01
		Maximum	0.40	1.41
		Mean	0.35	1.21
	Family health centre – 2	Minimum	0.22	0.78
		Maximum	0.30	1.06
		Mean	0.26	0.92
	Family health centre – 3	Minimum	0.64	2.24
		Maximum	0.78	2.72
		Mean	0.71	2.48
Kadirli	Public hospital	Minimum	0.06	0.20
		Maximum	0.71	2.47
		Mean	0.28	0.97
	Family health centre – 1	Minimum	0.14	0.50
		Maximum	0.20	0.71
		Mean	0.17	0.61
	Family health centre – 2	Minimum	0.31	1.08
		Maximum	0.41	1.44
		Mean	0.36	1.26
	Family health centre – 4	Minimum	0.44	1.54
		Maximum	0.54	1.89
		Mean	0.49	1.72
General		Minimum	0.06	0.20
		Maximum	0.78	2.72
		Mean	0.29	1.02

AED: annual effective dose; ELCR: excess lifetime cancer risk.

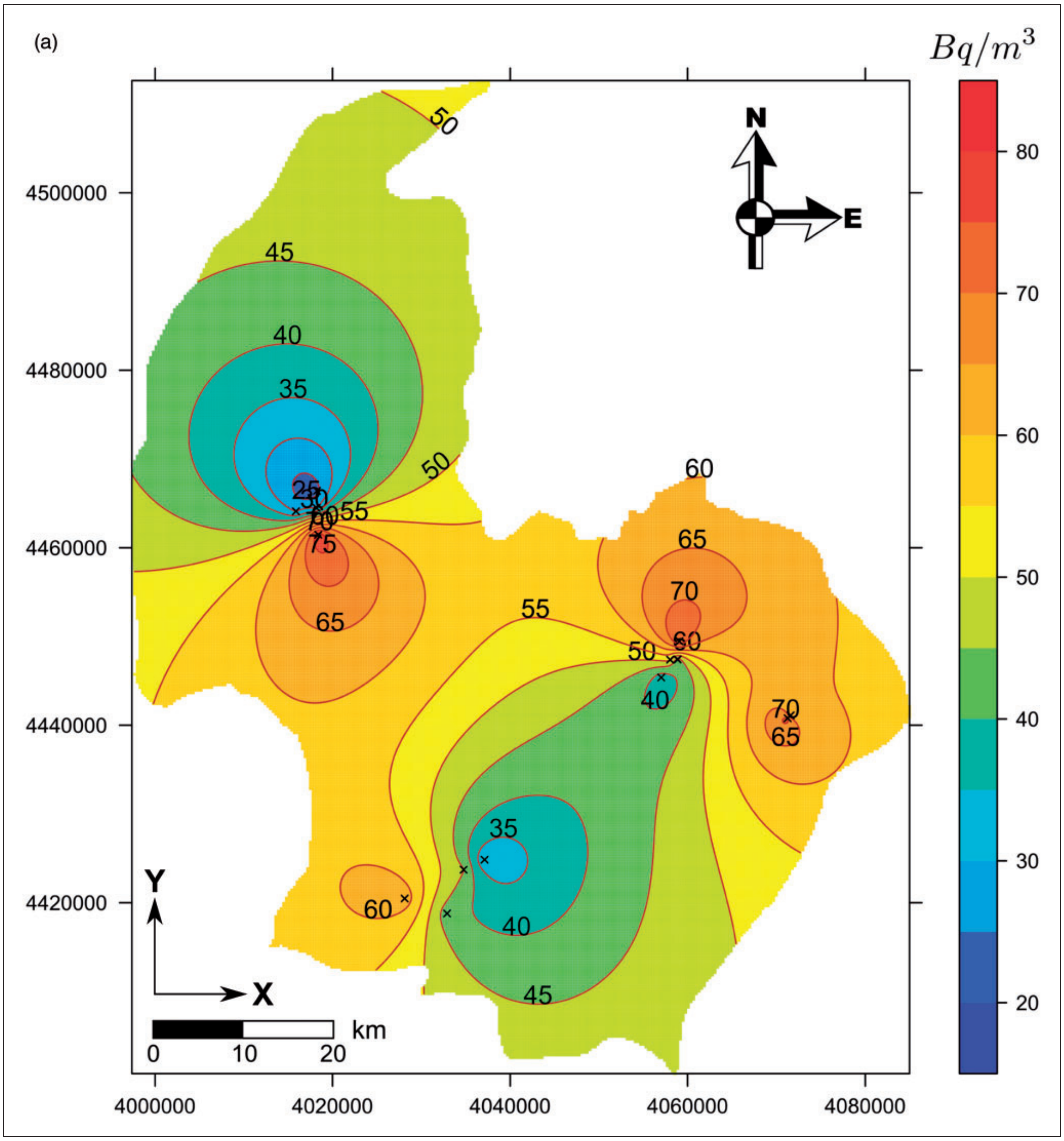

Figure 4. (a) Estimation map of indoor radon concentration. (b) Estimation map of AED. (c) Estimation map of ELCR.

The frequency distribution of radon concentrations found by this research is shown in Figure 2.

The figure illustrates a frequency distribution similar to a log-normal pattern. The statisticial results of indoor radon concentration in the study are outlined in Table 2.

Indoor radon concentrations in the study varied from 8 to 108 $Bq{\cdot}m^{-3}$ and with an arithmetical mean of 40 $Bq{\cdot}m^{-3}$ and 33 $Bq{\cdot}m^{-3}$ as geometric mean. The skewness and kurtosis values for frequency distribution of radon concentration were found to have positive values. The positive values of the skewness coefficients indicate that the distributions are asymmetric with the right tail that is longer than the left tail, and the positive value of kurtosis coefficient indicates that distribution is higher and narrower than normal. When the average indoor radon concentrations for the study is compared with the other studies already presented, the mean indoor radon concentrations observed in this work are higher than that of Iraq (Erbil),[16] the results of which are lower than those of Slovenia,[15] Iraq (Thiqar)[20] and the range of the action level of 200–600 $Bq{\cdot}m^{-3}$, advised by the International Commission on Radiological Protection (ICRP)[21] and is in concordance with findings for buildings worldwide.[1]

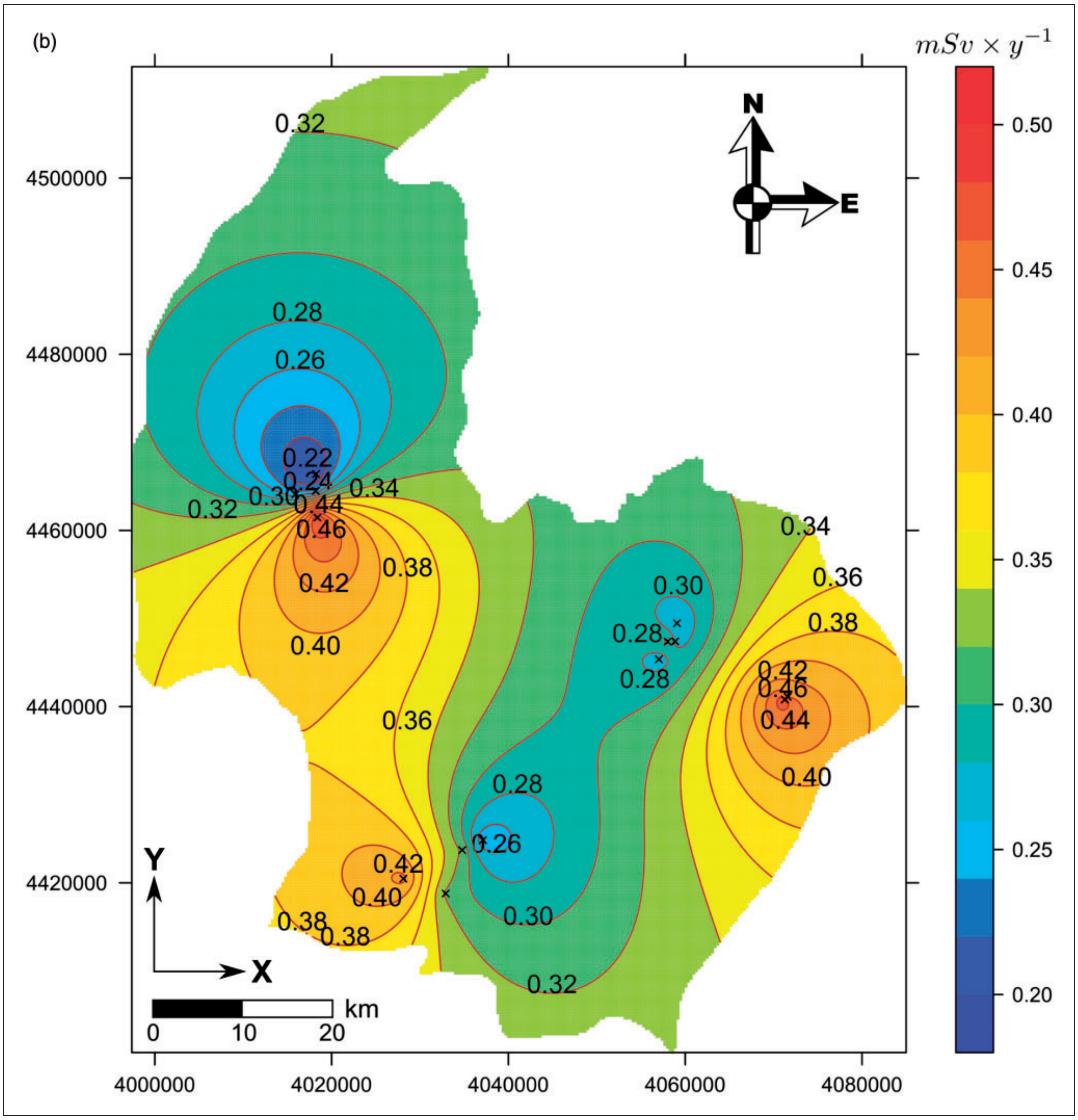

Figure 4. Continued.

The concentrations of indoor radon were found to change from place to place. According to each district, indoor radon concentration sampling is depicted in Figure 3.

As shown in the figure, the highest mean activity concentration of indoor radon was determined in the health centre in district of Düziçi, and the lowest mean concentration of indoor radon was found in the health centre in the city centre. The mean activity of indoor radon concentrations fell in the following order: ground floor (mean: 49 $Bq\,m^{-3}$) > first floor (mean: 21 $Bq{\cdot}m^{-3}$) > second floor (mean: 16 $Bq{\cdot}m^{-3}$). This variation may be attributed to ventilation, humidity, temperature, climatic conditions, and soil permeability which can be better for upper floors than that of ground floors, as upper floors were found to have better air circulation. Most of the rooms in health centres are naturally ventilated, that is to say by means of operable windows. Accordingly, the radon concentrations in the rooms can be due to the variations in ventilation conditions and air changes between the rooms.

The AED from inhalation of radon was computed applying equation (1)[1]

$$AED = DCF \times C_{Rn} \times F \times \tau \qquad (1)$$

where AED is the AED ($mSv{\cdot}y^{-1}$), DCF is the dose conversion factor converting radon concentration into effective dose which is 9×10^{-9} Sv $(Bq\ h\ m^{-3})^{-1}$, C_{Rn} is

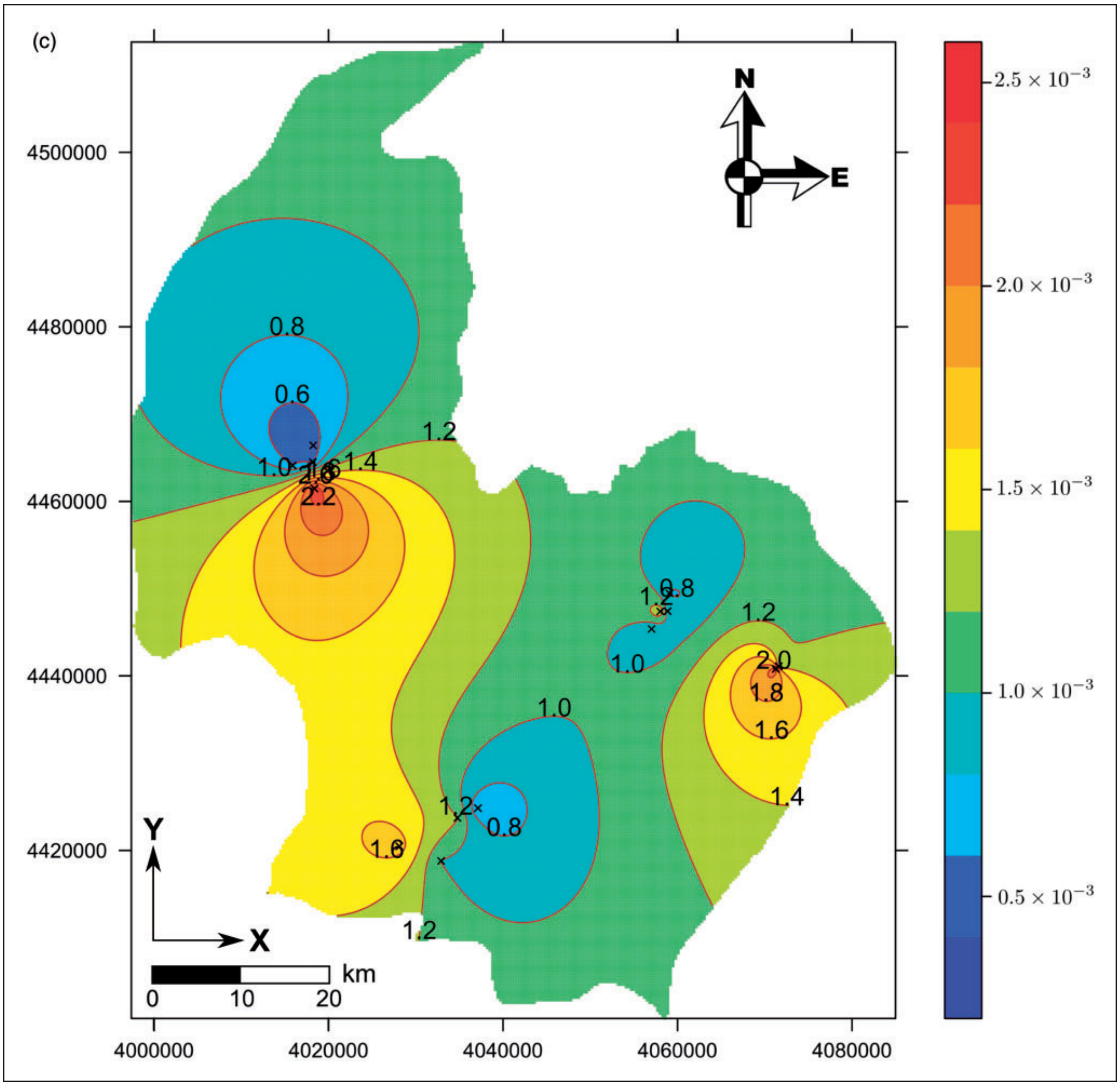

Figure 4. Continued.

the radon concentration (Bq·m^{-3}), F is the equilibrium factor (which is taken as 0.4), and τ is the occupancy factor (2000 h.y^{-1}). The corresponding AED values are presented in Table 3.

The AED values ranged from 0.06 mSv·y^{-1} to 0.78 mSv·y^{-1} with a value of 0.29 mSv·y^{-1}. The mean AED value was found to be at minimum in the city centre (0.23 mSv·y^{-1}) and was at maximum in Düzici district (0.34 mSv·y^{-1}). The current data showed less than the suggested action level (3–10 mSv·y^{-1}). Therefore, the findings have indicated that the results were safe as far as health hazard is concerned owing to indoor radon concentrations.

ELCR was computed based on equation (2)

$$\mathrm{ELCR} = \mathrm{AED} \times \mathrm{DL} \times \mathrm{RF} \qquad (2)$$

where AED, DL, and RF are the AED, duration of life (70 years), and risk factor (0.05 Sv^{-1}), respectively. The computed ELCR values are shown in Table 3. The ELCR values were found to be in the range of 0.20×10^{-3}–2.72×10^{-3}, with an overall average value of 1.02×10^{-3}. The maximum value of ELCR was observed in the family health centre-3 in Düziçi district, while the minimum value was found in Public Hospital in Kadirli district.

Since the number of detectors we had was limited, we could not deliver them to all districts, so to cover wide area of Osmaniye population predominantly, interpolation maps were generated with ordinary Kriging method[22,23] using R programing language[24,25] and quantum geographic information system (QGIS).[26] This method was used to interpolate and envisage unmeasured spots over the surveyed areas.[27,28] Interpolated estimated maps of study areas for indoor radon concentration, AED, and ELCR are shown in Figure 4(a) to 4(c), respectively. These maps indicate that there is density in indoor radon concentrations and AED and ELCR values in the central parts of the region, while the density decreases gradually towards the edges of the region.

Conclusion

This study was carried out in health centres in Osmaniye province, Turkey. Our findings should present information about radon activity concentrations and radiological parameters being exposed by staffs/patients in the health centre buildings. Indoor radon concentration values in the study area was shown to vary from 8 to 108 $Bq \cdot m^{-3}$ with a mean of 40 $Bq \cdot m^{-3}$. The radon concentrations decrease with increasing of floor levels. Corresponding radiological parameters have been estimated from the measured activities of radon, using the dose coefficients proposed by the UNSCEAR and ICRP. The mean values of AED and ELCR computed were found to be 0.29 $mSv \cdot y^{-1}$ and 1.02×10^{-3}, respectively. The findings were compared to other works and internationally verified values. The obtained measurements and interpolated predictions were used to map the distribtion for the region using with ordinary Kriging method based on R programing language and QGIS. Throughout the findings obtained, no health risks concerning radon activities exist for the hospital staff and patients in studied hospitals and health centres. The outcomes of the present study will help future researchers to establish a baseline to deal effectively with radiation emergencies as a safety precaution for radon concentrations.

Authors' contribution

All authors contributed equally in the preparation of this article.

Acknowledgements

The authors would like to thank the Health Manager of the city, and the cooperation of the Health centre directors and staff is appreciated. The authors would also like to kindly thank the experienced English lecturer of Batman University, Ihsan Pilatin, for his editing of the paper thoroughly.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article

References

1. UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation). *Sources and effects of ionizing radiation*. Report of the United Nations Scientific Committee on the effects of Atomic Radiation to the general assembly, 2000. New York, NY: United Nations Sales Publication.
2. Pearce J and Boyle P. Examining the relationship between lung cancer and radon in small areas across Scotland. *Health Place* 2005; 11: 275–282.
3. Magged AF. Estimating the radon concentration in water and indoor air. *Environ Monit Assess* 2009; 152: 195–201.
4. Abd El-Zaher M. Seasonal variation of indoor radon concentration in dwellings of Alexadria city, Egypt. *Radiat Prot Dosim* 2011; 143: 56–62.
5. Cevik U, Kara A, Celik N, Karabidak M and Celik A. Radon survey and exposure assessment in karaca and çal caves, Turkey. *Water Air Soil Pollut* 2011; 214: 461–469.
6. Mostafa AMA, Yamazawa H, Uosif MAM and Moriizumi J. Seasonal behavior of radon decay products in indoor air and resulting radiation dose to human respiratory tract. *J Radiat Res Appl Sci* 2015; 8: 142–147.
7. Risica S. Legislation on radon concentration at home and at work. *Radiat Prot Dosim* 1998; 78: 15–21.
8. Lundin FE, Wagoner JK, and Archer VE. *Radon daughter exposure and respiratory cancer, qualitative and temporal aspects*. Joint Monograph No. 1, NIOSH and NIEHS, 1971. Washington, DC: US Department of Health Education and Welfare, Public Health Service.
9. Sevc J, Kunz E and Placek V. Lung cancer in miners and long term exposure to ^{222}Rn daughter products. *Health Phys* 1978; 30: 433–437.
10. ICRP (International Commission on Radiological Protection). *Protection against* ^{222}*Rn at home and at work*. ICRP Publication 65, Annals of the ICRP 23(2), 1993. Oxford, UK: Pergamon Press.
11. Marley F, Denman AR and Phillip PS. Studies of radon and radon progeny in air conditioned rooms in hospitals. *Radiat Prot Dosim* 1998; 76: 273–276.
12. Korhonen P, Kokotti H and Kalliokoski P. Survey and mitigation of occupational exposure of radon in workplaces. *Build Environ* 2000; 35: 555–562.
13. Denman AR, Lewis GTR and Brennen SE. A study of radon levels in NHS premises in affected areas around the UK. *J Environ Radioactiv* 2012; 63: 221–230.
14. Mnich Z, Karpinska M, Kapala J, Kozak K, Mazur J, Birula A and antonowicz K. Radon concentration in hospital buildings erected during the last 40 years in Bialystok, Poland. *J. Environ Radioactiv* 2004; 75: 225–232.
15. Vauptic J and Kobal I. Radon survey and exposure assessment in hospitals. *Radiat Prot Dosim* 2006; 121: 158–167.
16. Ahmed AH, Haji SO and Azeez HH. Radon dosimetry in erbil city hospital. *J Phys Appl* 2012; 2: 240–244.
17. Radosys. User's manual 2000, www.radosys.com (2013, accessed 13 January 2015).
18. Celebi N, Ataksor B, Taskin H and Albayrak Bingoldag N. Indoor radon measurements in Turkey dwellings. *Radiat Prot Dosim*. Epub ahead of print 11 November 2014. DOI: 10.1093/rpd/ncu329.
19. Kucukomeroglu B, Ozturk E, Damla N, Celik N, Uzun Duran S, Cevik U, Taskin H and Albayrak N. Indoor radon and gamma spectrometric measurements for the erzincan basin on north anatolian fault zone, Turkey. *Indoor Built Environ*. Epub ahead of print 1 June 2015. DOI: 1420326X15588329.
20. Al Khalifa IJ and Mohamed AA. Indoor radon measurement in hospital and health centre, in Thiqar Governorate (Iraq) by using LR 115 type II (SSNTD). *IJRANS* 2014; 2: 1–6.

21. ICRP (International Commission on Radiological Protection). *Recommendations of the International Commission on Radiological Protection*. ICRP Publication 60, Report no. 1–3, Vol. 21, 1990. Ontario: ICRP.
22. Krige DG. Two-dimensional weighted moving average trend surfaces for ore-evaluation. *J South Afr Inst Min Met* 1966; 66: 13–38.
23. Matheron G. Principles of geostatistics. *Econ Geol* 1963; 58: 1246–1266.
24. Pebesma EJ and Bivand RS. Classes and methods for spatial data in R. *R News* 2005; 5: 9–13.
25. Pebesma EJ and Wesseling CG. Gstat: a program for geostatistical modelling, prediction and simulation. *Comput Geosci* 1998; 24: 17–31.
26. Quantum GIS Development Team. Quantum GIS geographic information system. Open source geospatial foundation project, http://qgis.org (2014, accessed on 25 February 2015).
27. Kobya Y, Taşkın H, Yeşilkanat CM, Çevik U, Karahan G and Çakır B. Radioactivity survey and risk assessment study for drinking water in the Artvin province, Turkey. *Water Air Soil Poll* 2015; 226: 49–57.
28. Kobya Y, Taşkın H, Yeşilkanat CM and Çevik U. Evaluation of outdoor gamma dose rate and cancer risk in artvin province, Turkey. *Hum Ecol Risk Assess*. Epub ahead of print 2 March 2015. DOI:10.1080/10807039.2015.1017876.