Indoor radon levels in the dwellings of the Gaza governorate neighborhoods', Palestine

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ABSTRACT

Background*:** Worldwide, indoor radon exposure is considered to be the second leading cause of lung cancer, particularly among people who stay indoors for a long time as the children and the elderly. The goal of this study is to get a better understanding of indoor radon levels in the houses of the Gaza governorate. ***Materials and Methods*:** One hundred eighty passive diffusion radon dosimeters containing CR-39 solid state nuclear track detectors (SSNTD) were distributed in the rooms of the Gaza governorates houses following a cluster random sampling. Only 154 dosimeters were found in the places and collected, while the remaining 26 dosimeters were lost. The detectors were left for two months during the period from March to June of 2006. Variability between dwellings neighborhoods, floors, rooms at the same floor, ventilation status, smoking, dwelling age were assessed. ***Results: The indoor radon concentrations in the houses of Gaza governorate were lower than the EPA and ICRP recommended limits (150 Bq/m3), with a mean indoor radon concentration (mean±SD) of 40±14 Bq/m3 and a range from 3 to 105 Bq/m3. The house ventilation status was the key variable which affects the indoor radon level, since badly ventilated houses had higher indoor radon concentrations, particularly in the basement floors rather than the higher floors. ***Conclusion:*** Despite fulfilling the international limits, we strongly recommend conducting a wider national survey for natural radiation measurements and mapping radon-borne areas throughout the country. Moreover, well ventilation of the house indoor environment is highly recommended.

***Keywords:** CR-39, dosimeters, detectors, Gaza governorate, buildings, indoor radon.*

INTRODUCTION

Over the past few years, indoor radon emissions and health risks attributed to accumulative exposure were the subject of scientific and regulatory attention worldwide. Radon is an inert, colorless, odorless, and tasteless noble radioactive gas, occurs mainly naturally through the uranium decay series that is presented naturally in soil, water, and building materials [1, 2].

The two main ways for radon to transfer into indoor air are diffusion and convection flows. In this regard, transmission of radon into the air through diffusion and its high concentration in the enclosed spaces such as underground mines or houses vary according to radium level in soil, rocks, and building materials as internal influences. However, atmospheric pressure, temperature, humidity, and wind speed are all considered as external influences [3, 4].

The divergences in the geology of the subsoil, climate, construction materials constituents', etc. lead to significant differences in indoor radon concentration levels among the countries, as well as among various parts of the country [5-7]. Radon level can vary even in the same dwelling and in general, is higher in basements and poorly ventilated places as well as unpainted places. In addition, radon concentration fluctuates daily depending on weather conditions and the habits of dwelling occupants [8, 9].

It is also noteworthy that almost fifty percent of the overall annual dose of human exposure from the natural radiation is attributable to radon and its daughters or progeny such as ^{218}Po and ^{214}Po, as their decay emitting heavy ionizing radiations called alpha particles. Since, worldwide average annual effective dose from ionizing radiation from natural sources is estimated to be 2.4 mSv, of which about 1.0 mSv is due to radon exposure [10]. Moreover, according to ICRP recommendations, the residential radon is regulated by an action level of radon concentration between 200 and 300 Becquerel's per cubic meter (Bq/m^3) [11]. Inhaling high concentrations of radon has been classified as a human carcinogen by the International Agency for Research on Cancer and it is categorized worldwide as the second major cause of lung cancer, basically due to its interaction with biological tissue in the lungs leading to DNA damage [12-15].

According to a cancer report by the Palestinian ministry of health in 2015, acute and chronic respiratory diseases are remarkably spread among the Gaza's population as well as lung cancer [16]. Indoor radon exposure has become a problem all over the world confirmed by many large-scale studies that have been conducted throughout the world to measure indoor radon concentration and to assess the health problems attributable to its inhalation [17]. However, to the best of our knowledge, there is limited information regarding public exposure to indoor radon in the Gaza strip. Therefore, such a study becomes more important due to Gaza's high population density and to add further explanations for the high prevalence of respiratory diseases and lung cancer in our region. Hence, this study aimed to determine the radon concentrations in the houses of Gaza governorate in order to reach a better understanding of the potential health risks from the natural radioactive source in Gaza. Furthermore, the outcomes of our present work will be used to establish a national database regarding the radiation hazards and mapping radon-borne areas throughout the country.

MATERIALS AND METHODS

Study area

The Gaza governorate is one of the five governorates of Gaza strip, located in the north-central Gaza strip. According to the Palestinian Central Bureau of Statistics, the governorate's population was 696,410 in 2017 with a surface area of 70 Km^2 (figure 1). The area is subjected to a semiarid Mediterranean climate. Most of the governorate is covered by quaternary soil, with a clayey material. It has a temperate climate, with mild winter, and dry, hot summer. The terrain is flat or rolling, with dunes near the coast, the highest point is about 105 meters above sea level. Natural resources include arable land which is mostly irrigated and natural gas which was discovered recently. All building materials, in Gaza strip, are imported from occupied Palestine and have never been monitored to ensure compliance with relevant standards. Most of the buildings in the region of study are made up of concrete and few buildings of asbestos and stone [18].

Sampling process and detectors locations

A cluster random sampling method was followed in this study, in which the detectors were proportionally distributed on the eight neighborhoods of the Gaza strip according to the houses number in each neighborhood. One hundred eighty dosimeters were prepared and located in the dwellings of Gaza governorates neighborhoods as follows: 40 at Al-Remal, 20 at Al-Shatee, 20 at Al-Sheikh Redwan, 20 at Al-Sabra, 20 at Al-Shejaiya, 20 at Al-Darge, 20 at Al-Nazla, and 20 at Al-Zaiton neighborhood. The detectors were put in the kitchens, bedrooms, and living rooms at different floor levels ranged from the basement floor to fourth floor for two months from March to June of 2006. Only 154 dosimeters were found in the places and collected, while the remaining 26 dosimeters were lost. The United States Environmental Protection Agency (USEPA) indoor radon and radon decay product measurement device protocols were taken into account when selecting the location of detectors [19].

Figure 1. Gaza strip map and study area.

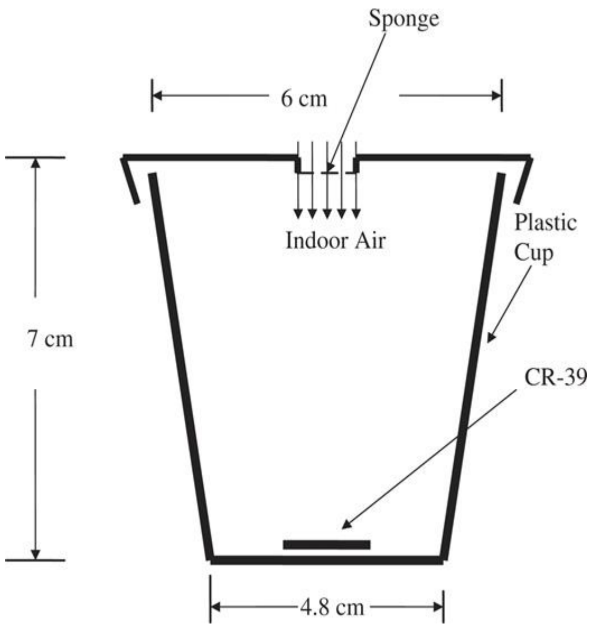

Figure 2. Schematic diagram of the radon CR-39 dosimeter placement.

Radon measurements in dwellings

Passive diffusion radon dosimeter containing CR-39 solid state nuclear track detectors (SSNTDs) of super grade quality (CR-39, poly allyldiglycol carbonate, named PADC) were purchased from Intercast Co, Parma-Italy and used in this survey [20, 21]. The structure of the passive dosimeter is a plastic cup 7 cm height, 6 cm diameter at one end, and 4.8 cm at the other end (figure 2), where a plastic SSNTD with 1×1 cm^2 was fixed. The end of the cup opposite to the detector is covered with a plastic with a hole which in turn is covered by a piece of sponge into the interior surface.

The collected detectors were immersed in the etching solution of sodium hydroxide solution with concentration of 1 mol/ liter (NaOH; CAS 1310-73-2, Merck Millipore, Germany), at a temperature of 70 ^{o}C for 6 hours, in a small container inside a water bath. At the end of the etching process, the detectors were washed thoroughly with distilled water. Then, they were dried and afterwards counted visually using a digital optical microscope with built-in camera and with 400X magnification power (Optika Company, Italy).

The tracks density is calculated using the equation 1 [22]:

$$Track\ density\ \left(\frac{track}{cm^2}\right) = \frac{Average\ number\ of\ total\ track}{View\ field\ of\ area} \quad (1)$$

Radon concentration (C) in the surrounding air was determined using Equation 2 in terms of Bq/m^3, the most regulatory reference unit [23-26].

$$C\left(\frac{Bq}{m^3}\right) = \frac{C_0\,(Bq.\frac{d}{m^3})}{\rho_0}\left(\frac{\rho}{t}\right)_{det.} \quad (2)$$

Where, C_0=the total exposure of ^{226}Ra (Radon source) in term Bq.d/m^3, r_0=track density (number of tracks/cm^2) of detectors exposed to ^{226}Ra, r=track density (number of tracks/cm^2) of distributed detectors, t= exposure time (days) of distributed detectors.

$$\frac{C_0\,(\frac{Bq.day}{m^3})}{\rho_0\,(\frac{track}{cm^2})} \quad (3)$$

Where, (C_0/r_0) is calibration factor for dosimeters exposed (it gives (0.0216 ± 0.0033)) [(Bq.day/m^3) per (track/cm^2)].

Quality assurance

EPA guidance [27] for quality assurance has been adopted to make sure that the results of the present study are reliable, accurate and precise. Therefore, measurements in duplicates (10% of all detectors) in addition to blank measurements (5% of detectors) were conducted.

Data analysis

The data collected in this study were analyzed using an Excel spreadsheet. The data analysis was also based on the different parameters that may affect indoor radon concentration levels, mainly: neighborhood location, building age, smoking habits of house residents and floor level, and ventilation status. The results of indoor radon concentrations were presented in tables in terms of mean and standard deviation.

RESULTS

Table 1 shows the outcomes of indoor radon concentration measurements in eight neighborhoods of Gaza governorate. Overall, the indoor radon levels were low, with a mean indoor radon concentration (mean±SD) of 40±14 Bq/m^3. The levels were exactly ranging from 3 to 105 Bq/m^3. This large variation between the minimum and maximum readings is mainly due to the differences in the geographical areas, building age and materials, ventilation level, height of the floor, etc. However, no reading exceeded 105 Bq/m^3.

As indicated in table 2, the average of indoor radon concentrations varies from one building to another within the same height but in a different region. Also, they were different from one floor to another in the same building. The highest average of indoor radon concentration (43 Bq/m^3) was found in the basement floors.

The results in table 3 revealed that the average of indoor radon concentrations varied from one room to another on the same floor. The average indoor radon concentration was found to range from a minimum value of 16.15 Bq/m^3 determined in bedrooms to the maximum value of 57.30 Bq/m^3 detected in the living room. Table 3 also shows that the highest average indoor radon concentration (41 Bq/m^3) was found in kitchens.

Table 4 exhibits that the variation of the average indoor radon concentrations according to the smoking habit of the residents. The mean of indoor radon concentrations among non-smokers' houses (33 Bq/m^3) was higher than among smokers' houses (42 Bq/m^3).

In the present study, the age of the buildings was divided into four groups as seen in table 5. Generally speaking, the old buildings have higher indoor radon concentrations than the newest buildings.

The indoor ventilation status in this work was classified into three groups as presented in table 6. The bad ventilated house was with small windows or windows being opened for less than three hours a day, the intermediate ventilated house was with windows being opened for three to eight hours daily, and the well-ventilated house was with windows being opened for more than eight hours a day. Our results showed that badly ventilated houses had the highest indoor radon levels while well-ventilated houses had the lowest indoor radon levels. Besides, variation in indoor radon concentrations in the houses with similar ventilation status but in different regions.

Table 1. Summary analysis of the average indoor radon concentrations in the Gaza governorate neighborhoods.

Neighborhood	No. of detectors	Mean ±SD of Radon Concentration (Bq/m^3)	Max (Bq/m^3)	Min (Bq/m^3)
Al-Remal	40	36±19.94	105	3
Al-Shatee	21	38±16.62	67	8
Al-Sheikh Redwan	20	46±15.39	68	11
Al-Sabra	11	34±13.31	55	13
Al-Shejaiya	21	35±16.62	97	14
Al-Darge	14	42±21.05	83	8
Al-Nazla	15	34±13.31	55	13
Al-Zaiton	12	40±14.47	86	13
	Sum=154	**Mean ±SD=39.12±17.02**	**Mean=80.50**	**Mean=9.50**

Table 2. The average indoor radon concentrations according to the floor of the detectors' location in the house.

Neighborhood	Basement floor (Bq/m^3)	1st floor (Bq/m^3)	2nd floor (Bq/m^3)	3rd floor (Bq/m^3)	4th floor (Bq/m^3)	5th floor (Bq/m^3)
Al-Remal	42.8	41.73	-	39.49	-	37.68
Al-Shatee	42.09	34.80	-	29.60	-	-
Al-Sheikh Redwan	52.05	38.43	30.07	-	27.25	-
Al-Sabra	43.77	31.98	-	-	-	-
Al-Shejaiya	35.21	33.69	35.24	-	-	-
Al-Darge	51.14	42.83	31.21	-	-	-
Al-Nazla	41.8	13.93	-	-	-	-
Al-Zaiton	41.28	27.7	32.11	-	-	-
Mean (Bq/m^3)	**43.77**	**33.14**	**32.16**	**34.54**	**27.25**	**37.68**
No. of detectors	**54**	**50**	**19**	**8**	**3**	**2**

Table 3. The average indoor radon concentrations according to the place of the detectors' location in the house.

Neighborhood	Bedroom (Bq/m^3)	Living room (Bq/m^3)	Kitchen (Bq/m^3)
Al-Remal	50.82	41.8	41.97
Al-Shatee	37.49	57.30	33.57
Al-Sheikh Redwan	36.22	42.7	53.97
Al-Sabra	50.32	34.44	28.44
Al-Shejaiya	37.29	25.66	39.06
Al-Darge	31.82	48.21	40.68
Al-Nazla	16.15	27.23	46.23
Al-Zaiton	30.66	32.11	45
Mean (Bq/m^3)	**36.3465**	**38.68125**	**41.115**
No. of detectors	**53**	**45**	**42**

Table 4. The average indoor radon concentrations according to smoking habit of residents.

Neighborhood	Non-smoking (Bq/m^3)	Smoking (Bq/m^3)
Al-Remal	38.5	47.65
Al-Shatee	39.65	49.46
Al-Sheikh Redwan	42.4	38.34
Al-Sabra	32.69	44.35
Al-Shejaiya	29.89	38.48
Al-Darge	33.63	47.65
Al-Nazla	17.79	40.08
Al-Zaiton	33.43	34.24
Mean (Bq/m^3)	**33.49**	**42.53**
No. of detectors	**62**	**78**

Table 5. The average indoor radon concentrations according to age of the building.

Neighborhood	<10 yeas (Bq/m^3)	10-20 years (Bq/m^3)	20-30 years (Bq/m^3)	30-40 years (Bq/m^3)	>40 years (Bq/m^3)
Al-Remal	38.33	45.51	40.85	31.82	54.79
Al-Shatee	40.17	41.44	44.62	43.47	43.42
Al-Sheikh Redwan	39.74	37.82	45.86	-	-
Al-Sabra	38.30	42.93	-	-	-
Al-Shejaiya	34.62	37.66	33.31	-	-
Al-Darge	33.55	-	-	-	-
Al-Nazla	15.04	23.94	43.83	-	-
Al-Zaiton	35.39	32.93	-	-	45.36
Mean (Bq/m^3)	**34.39**	**37.46**	**41.69**	**37.64**	**47.86**
No. of detectors	**53**	**40**	**20**	**6**	**8**

Table 6. The average indoor radon concentrations according to the ventilation level

Neighborhood	Well ventilation (Bq/m^3)	Intermediate ventilation (Bq/m^3)	Bad ventilation (Bq/m^3)
Al-Remal	39.6	44.09	44.11
Al-Shatee	38.28	40.4	43.07
Al-Sheikh Redwan	37.67	38.83	56.31
Al-Sabra	29.93	37.56	55.84
Al-Shejaiya	24.65	37.26	42.40
Al-Darge	35.33	51.22	76.98
Al-Nazla	27.01	49.71	-
Al-Zaiton	31.40	35.33	45.36
Mean (Bq/m^3)	**32.98**	**41.80**	**52.01**
No. of detectors	**86**	**29**	**22**

DISCUSSION

The detailed measurements for indoor radon concentration levels were made in eight neighborhoods of Gaza governorate using 145 detectors at different floors height, rooms, building ages, smoking habits, and ventilation conditions. In some cases, the high values of radon concentration in well ventilated dwellings could be attributed to the high concentration of radon in the used building materials. On the other hand, the lower radon concentration observed in some of the partially ventilated houses in comparison to well ventilated houses could be due to the cellar (basement) construction in the dwellings.

It could be concluded from this data that the indoor concentration attained in the present investigations, varied from 3 to 105 Bq m^3, with overall average value 40 Bq/m^3 and with a standard deviation of 14 Bq/m^3, which is lower than the recommended ICRP action level of 200–300 Bq m^3 [(11)]. A similar type of trend has already been reported in the preceding researches carried out in this geographical area [(28-31)]. The large variation between the minimum and maximum measurements of radon concentration (3 and 105 Bq/m^3) is mainly due to the differences between the regions in terms of geographical area, building age and materials, the height of floor, ventilation level, etc. Consequently, our results highlight that indoor radon concentrations levels differ from one neighborhood to another.

It could be transpired from the results that the bedrooms of the dwellings have higher Rn concentrations than the living rooms. This may be due to the fact that the living rooms generally have higher ventilation rates than the bedrooms since ventilation is crucial for fresh healthy air and can reduce radon exposure. The higher kitchen levels in all dwellings is basically attributable to the use of fuels such as cooking gas, i.e. liquid petroleum gas or other fuels and use of water which alleviates the Rn concentration [(32)].

The decreased Rn levels noticed in the higher floors of the building is in consistence with the results of earlier studies [(32, 33)]. The Rn concentration gradually decreases as the altitude increases, and the contribution in higher floors to the indoor Rn levels is mostly attributed to building materials. Furthermore, it was reported by many researchers that the reduced ventilation increases the indoor Rn levels [(34-36)] and hence, ventilation plays a major role inside the buildings, as long as the Rn problem is of critical importance.

Indoor radon concentration levels were higher in old buildings that often have more cracks and poor painting than new buildings. Moreover, basement floors close to soil had more indoor radon concentration whereas higher floors had lower concentrations. Therefore, in designing new houses, it is important that the construction of the floor touching the ground be crack-free and airtight, which will reduce the buildup of radon inside houses [(1, 2, 7)].

It is well evidenced that a synergism between smoking and radon increase the occurrence of lung cancer as many radon-related deaths could be realized by quitting smoking [(37)].

CONCLUSION

The indoor radon concentrations in the dwellings of Gaza governorate were lower than the EPA and ICRP recommended limits (150 Bq/m^3). The house ventilation status was the key variable affects the indoor radon level, since badly ventilated houses had higher indoor radon concentrations, particularly in basement floors rather than the higher floors. The indoor radon concentration in non-smokers' houses was higher than in smokers' houses. Despite fulfilling the international limits, we strongly recommend conducting a wider national survey for natural radiation measurements and mapping indoor radon-borne areas throughout the Gaza strip.

LIMITATIONS

Seasonal variations in indoor radon concentrations were not taken into account in this study.

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