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# Estimation of indoor radon concentration and dose evaluation of radon and its progeny in selected dwellings in Duhok city, Kurdistan Region, Iraq

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► ***Original article***

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***Keywords:*** *Radon monitoring, Indoor radon, annual effective dose, metrological parameters and ventilation.*

## ABSTRACT

***Background***: Among the natural radioactive sources, two-thirds of radiation dose received by living tissue is caused by radon and its progeny because it can interact with biological tissue when it is inhaled or ingested. Accordingly, this study planned to measure indoor radon and evaluates its doses in addition to studying metrological parameter to understand the correlation between them. ***Materials and Methods***: This study focused on the indoor radon concentration by two different protocols which are short term and long term. In short term, radon concentration was measured in seven dwellings in Duhok city at the beginning of both winter and summer using RAD7 detector and Airthings Corentium monitor. Then annual effective dose of radon and its decay product to the inhabitance were estimated. In long term protocol, radon concentration was measured continually for one year by fixing Corentoum detector in one building. ***Results***: outcomes showed that the concentration of radon is higher in winter than summer; with range of 1-56 Bq $m^{-3}$. The average level of indoor radon concentration in both seasons was 19 ± 6.1 Bq $m^{-3}$. The radon and its progeny average annual effective dose were 0.59 ± 0.17 and 0.23 ± 0.14 mSv $y^{-1}$ in winter and 0.37 and 0.15 mSv $y^{-1}$ in summer respectively. ***Conclusion***: The results of average indoor radon concentration obtained were considerably less than the action levels prescribed by ICRP. Also, the results indicated that radon concentration negatively correlated with wind speed and positively with outdoor temperature while outdoor humidity effect has almost neglected.

## INTRODUCTION

Radon ($^{222}Rn$), a member of uranium ($^{238}U$) decay series, is a radioactive gas with a half-life of 3.8 days presenting throughout the world by variety of quantities [1-2]. The radon gas presence in water, soil and rocks has extremely simplified the capability of human to predict and identify the events of earthquakes, faults dislocation and volcanic activity [3]. On the other hand, the major source of public exposure to natural radioactivity is the radon and its short-lived progenies. Radon concentrations in the environment are generally very low [4]. However, in indoor air it presence at high concentration poses hazard to human's health and is the most relevant reason of cancer diseases associated to lungs and respiratory tract among non-smokers [4]. When radon decays after ingestion or inhalation, it and its progeny emit energy which can damage DNA of stomach and lungs cells. The dose for the respiratory tract and the lungs is due to the deposition of radon daughter through aerosol particles [5].

Three principal sources of radon are found in indoor air. They are soils and rocks under buildings, construction materials utilized, and radon dissolved in the water supply [6]. Therefore, radon concentrations can vary from location to location and from building to building within the same area, as well as from season to season or day to day within the same building. According to Oni *et al.* (2012) [7], the level of radon gas in kitchens and bathrooms is higher than other rooms in the same building because of foils or water use. A significant number of studies were published through the last decades which discuss both various sources of indoor radon gas and its changes during the time and the diurnal drivers [8]. Building materials, building geology, metrological parameter and the ventilation degree of closed medium are among the significant parameters influencing the indoor radon concentration [8]. Radon concentrations are reportedly less sensitive to building characteristics than meteorological parameters [9].

The correlation of indoor radon level with metrological parameters is not compatible. Seasonal variation is the most common irregularity. For instance, lower concentrations of radon are often perceived in dwellings in the warm season and higher radon concentration in cold period [10]. Nevertheless, the opposite relation takes place in Alabama dwelling; during the summer radon have highest level [10]. The best demonstration for this variation is that in areas where temperatures are hotter, dwellings are tightly closed and ventilated during the milder months and air conditioned during the hottest months. It is very significant to measure the concentration of radon and its decay product in the living environment [11].

In Iraqi Kurdistan regain radon has been measured in indoor air in different hospitals [12], in indoor air of Erbil dwellings [13], and water of Darbandikhan Lake [14]. Indoor radon level has to date not been measured in dwellings of Duhok city- Northern Iraq. Therefore the aim of this research is measuring the level of radon in Duhok home and to evaluate its doses in order to be the reference data for future work. Furthermore, it has been found the correlation between seasonal variation and radon level. To assess the average annual radon concentration, long term integrated radon measurement are preferred. Most of the researchers use passive detector, while this research found with using of Corentium monitor much simple with minimal chance of error due to less interference, this plays a rather big role of this paper.

## MATERIALS AND METHODS

### *Study area and selection of dwelling*

The indoor radon was measured in the selected resident dwellings in seven various places of Duhok city. Duhok city is the capital of the Duhok provenance, located in the north-west of Kurdistan Region of Iraq. Generally Duhok is created of long extended of mountains, flat plains valleys, and hills. The altitude is quite different, ranging from 300 to more than 1300 metres above the sea level with three different northern, northeastern and western types of wind [15]. The geographical locations of the study areas are shown in the figure 1.

Historically, the heaviest precipitations in Duhok city begin in late winter and early spring, starting from November to May, which are the cooler months [15]. In 2019 the precipitation starts from end of December and last up to June 2020. This means that the draft period starts from June to December of 2019. Those selected buildings are constructed of cement and bricks plastered with gypsum. Table 1 shows more information about geographical and geological point of view.

### *Method of sampling*

Indoor radon concentrations were performed using a Corentium detector and a highly versatile instrument RAD7 detector to emphasize the accuracy of the results.

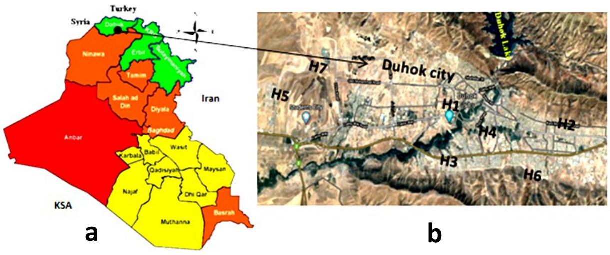


**Figure 1. (a)** Map of Iraq **(b)** Map of the city of Duhok.

**Table 1.** Geological and geographical information about selected dwellings.

| Sample code | Name of the area of the site | Dwelling description | North, East geographical location |
|---|---|---|---|
| H1 | Grebase | House, one floor with basement | 36°51'57.4, 42° 59'29.1 |
| H2 | Etit | Flat, First floor have basement | 36°50'23.6, 43° 04'34.3 |
| H3 | Shndoxa | House, one floor with basement | 36°51'06.0, 42° 57'25.4 |
| H4 | City center | House, two floor | 36°51'46.2, 42° 59'51.7 |
| H5 | Tenahi | House, one floor | 36°51'51.8, 42° 54'46.4 |
| H6 | Nzirke | House, Two floor | 36°50'57.0, 43° 03'12.5 |
| H7 | Misik one | House, one floor | 36°52'10.6, 42° 57'06.5 |

RAD7, which is made in U.S by DURRIDGE Company, is a true, direct, real-time continuous radon monitor which means different levels of radon concentration can be perceived during a period of measurement. This is very helpful for one who can investigate the factors affecting radon concentration with time. When radon is deposited on the surface of the detector, they radiate alpha particles of special energy immediately into the solid state detector [16-18]. Electrical signal is created by the detector, and then by electronic circuit this signal converts to digital form. When this detector is turned on one can see settings on the LCD display, this allows checking that the instrument is configured as required for intended use such as test duration, cycles and humidity. In this study RAD7 connected to dried plastic cylindrical tube filled with calcium sulfate ($CaSO^4$). The dried tube consists of two holes; one at the top to inter the air for measuring radon concentration and other in the bottom to exodus dried air.

Corentium detector is an electronic radon monitoring, model type; BQM-Digital, made by a Norway-based Technology Company in Norway [1]. To detect radon concentration the device take indoor air sample through a passive diffusion chamber, by utilizing alpha spectrometry. Radon gas is measured using silicon photodiodes to both count and measure the alpha particles energy as the consequence of the decay chain of radon. The accuracy of the detector is 200 Bq $m^{-3}$, for 7 days 10 % and for 2 months is 5 %. While, its relative humidity up to 85 % and temperature operation environment range from 3 °C to 40 °C.

Indoor radon was measured continuously in December (winter) 2019 in the study dwellings of Duhok city, as shown in figure 1 and table 1. For more accuracy and comparison both detectors were used. The detectors were placed in the living room 50 cm above the ground and approximately 150 cm away from the nearest doors, air vent or windows of each of the residential buildings, in order to catch radon in the air in these areas without interference. The study room of each dwelling was about 24 $m^2$ with one door and one window. In each residential building, radon concentration was measured by RAD7 four times at different time of day; each test was setup to four cycles each of about 30 minutes so that daily test duration became two hours. In each measurement the humidity of the RAD7 settled to below 6%. Finally the records concentration of radon in RAD7 converted to PC by a cable.

In the meantime, Corentium detector was allowed to stay for the whole day. Corentium detector LCD gives two results: one of them Short Radon Concentration (SRC) and other Long Radon Concentration (LRC) measurements. The long term means average of radon during the measured period of time while short term means instantaneous reading. The GPS reading and metrological parameter were also taken in each of these different dwellings to attain the geographical position of the study and evaluate the effect of temperature, wind speed and humidity while, to examine the influence of seasonal variation on results, the same procedure was repeated in the same positions of all selected dwellings in July (summer) 2020.

### *Dose assessment*

Radon and its decay products are the significant factors for assessing internal exposure. The equilibrium level, the conversion coefficient of radon dose, and time spent indoors are the main factors for finding the level of dose received by the dweller.

It is argued that recently the conversion factor suggested by UNSCEAR [19] has been called into question by the ICRP [20], which proposed a correction by a factor of 2 upwards. ICRP in 2017 published a paper which uses higher dose radon conversion factors, this leads to increase in estimation of radiation dose related with radon exposure in places of work [21]. However UNSCEAR has assured in a report published 2019 that the evidence revised by its experts is convenient with the previous data in the Committee's about the cancer risk [22]. Thus, UNSCEAR continued to use 9 nSv/ Bq h $m^{-3}$ as the dose conversion factor.

Hence different models were used to calculate the annual effective dose. In this study the annual effective dose from exposure to radon can be calculated by using equation 1 [7]:

$$AED\ (mSv\ y^{-1}) = T \times D \times F \times RC \quad (1)$$

Where: AED is the annual effective dose in mSv $y^{-1}$ from exposure to radon, T is the Occupancy time for indoor 7000 $hy^{-1}$ which is 80% office occupancy, D is the Dose conversion factor (9 nSv/ Bq h $m^{-3}$), RC is the average Radon level in Bq $m^{-3}$ and F = 0.4 is the value of indoor radon equilibrium.

The annual dose equivalent in soft tissues $D_s$ and the lung $D_L$ are calculated as equations 2 and 3 [1]: respectively.

$$D_s\ (mSv\ y^{-1}) = 0.09 \times 10^{-9}\ RC \quad (2)$$

$$D_L\ (mSv\ y^{-1}) = 0.80 \times 10^{-9}\ RC \quad (3)$$

Short-lived progenies of radon are responsible for the main contribution to the human exposure and one can obtain it by variety of methods [15-16] The concentration of indoor radon is converted into the Equilibrium Equivalent Radon Concentration (EEC) using equation 4 [18] which is further converted into Potential Alpha Energy concentration (PAE) using equation 5 [18]. Where 1 WL (Working Level) was known as the concentration of potential alpha energy related with the radon progeny in equilibrium with 3700 Bq $m^{-3}$ and equal to 2.08 x $10^{-5}$J $m^{-3}$) [19].

$$EEC = RC \times F \quad (4)$$

$$PAE\ (WL) = EEC\ /3700 \quad (5)$$

While, radon progeny annual effective dose DRE (mSv $y^{-1}$) is obtained by the use of equation 6 [7]:

$$DRE\ (mSv\ y^{-1}) = T \times D \times F \times EEC \quad (6)$$

### *Ventilation and metrological effect*

After comparing indoor radon concentration measured by RAD7 and Corentium detector, the accuracy and clarity of Corentium detector was emphasized. Therefore, to understand the effect of natural and forced ventilation and to investigate metrological parameter-dependent effects, an abandoned building is chosen (H6), in this building Corentium detector was fixed in living room for about one year (beginning of December 2019 to end of December 2020) indoor radon concentration was measured during the all-time. At the same time the metrological data base considered here are for the outdoor temperature, wind speed, humidity and precipitation percent from the official online website of Duhok weather (Accuweather). In this study winter season was defined to be from December to March while spring defined to include April and May, from June to August considered as summer and the September, October and November months considered as autumn.



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### *Statistical analyses*

Statistical analysis is a part of mathematical science dealing with data collection and is useful in drawing comprehensive conclusions about a series or set of data from samples selected from a total population. These data thereafter can be subjected to statistical analysis. The main study by the method of statistics analysis is to design the distribution of this series.

The science of statistics is used to organize, analyze, summarize and make predictions regarding the collected data. Many programing software packages have been developed to perform and calculate all aspects of statistical analysis, such as EXCEL, MATLAB, MATHEMATICA, PYTHON etc…The main parameters used in measurement of area are the maximum, minimum, mean, median and standard deviation, in addition to the p-value.

## RESULTS

Table 2 and 3 provide the fundamental statistical properties such as minimum, maximum and mean of indoor radon concentration in each dwelling in both winter and summer season of Duhok city respectively. The maximum value of RC recorded in winter 56 Bq m$^{-3}$ by Corentium detector in dwelling H5 and 49.5 Bq m$^{-3}$ by RAD7 in H3 while, in summer season 29 Bq m$^{-3}$ by Corentium detector and 29.5 Bq m$^{-3}$ by RAD7 in dwelling H3. The mean of indoor radon concentration recorded in summer is less than winter level in all seven dwellings. The arithmetic means of RC in winter and summer season were (24 ± 7 and 15 ± ± Bq m$^{-3}$) respectively which is lower than the mean of the world (40 Bq m$^{-3}$) [(6)]. *T-test* was done between RC recorded by Corentium monitor and RAD7 detector in both seasons, P-values were 0.5 in summer and 0.13 in winter. While P-value between RC recorded in summer and winter was 0.001 using both detectors.

Furthermore, table 2 and 3 give information about annual effective dose of radon AED, annual dose equivalent in soft tissues $D_S$ and annual dose equivalent in Lung $D_{L,}$ Equilibrium Equivalent Concentration (EEC), Potential Alpha Energy concentration (PAE) and the annual effective dose calculated from radon daughter DRE.

As an example, which reflect the behavior of RC in all dwellings, figure 2 A and 2 B plots the mean monthly and daily values of the radon concentration respectively over the investigation period in H6. One can see that RC fluctuates each hour, day and month.

Table 4 gives information about the values of RC, outdoor temperature, humidity and wind speed in various winter dates in one of the closed house (no ventilation). Statistical t-test demonstrates that a strong positive correlation ($R^2$ = 0.4) was found between outdoor temperature and indoor radon, and lesser correlation with humidity ($R^2$ = 0.02). However, radon concentration was observed negatively correlated with outer wind speed ($R^2$ = 0.19).

Table 5 shows comparison between present work and three local studies [(23-25)]. Also the comparison is carried out with eight of the worldwide investigations about the indoor radon studies.

**Table 2.** Minimum, maximum and average radon concentration measured by Corentium and RAD7 detector and dose assessment of radon and its progeny AED, $D_E$, $D_s$, $D_L$, EEC, PAE and RDE of the selected dwellings in winter season.

| Sample codes | RC measured by Corentium | | | RC measured by RAD7 | | | Dose assessment of radon and its progeny | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Av. RC ± SD Bq m$^{-3}$ | Min RC Bq m$^{-3}$ | Max RC Bq m$^{-3}$ | Av. RC ± SD Bq m$^{-3}$ | Min RC Bq m$^{-3}$ | Max RC Bq m$^{-3}$ | AED mSv y$^{-1}$ | $D_s$ mSv y$^{-1}$ x10$^{-9}$ | $D_L$ mSv y$^{-1}$ x10$^{-8}$ | EEC Bq m$^{-3}$ | PAE J m$^{-3}$ x10$^{-8}$ | DRE mSv y$^{-1}$ |
| H1 | 25.2 ± 1.7 | 15 | 39 | 23.6 ±2.4 | 20 | 26 | 0.59 | 2.12 | 1.88 | 9.44 | 5.3 | 0.23 |
| H2 | 23.4 ± 2.5 | 18 | 28 | 23 ±1.4 | 19 | 30 | 0.57 | 2.07 | 1.84 | 9.2 | 5.2 | 0.23 |
| H3 | 20.6 ± 1.8 | 23 | 47 | 21 ± 1.8 | 26 | 49.5 | 0.52 | 1.89 | 1.68 | 8.4 | 4.7 | 0.21 |
| H4 | 9.4 ± 0.8 | 1 | 15 | 11 ± 1.2 | 7 | 14 | 0.27 | 9.90 | 8.80 | 4.4 | 2.5 | 0.11 |
| H5 | 32 ± 3.7 | 19 | 56 | 32.5 ±3.1 | 22 | 39 | 0.81 | 2.92 | 2.60 | 13 | 7.3 | 0.32 |
| H6 | 27 ± 1.9 | 22 | 31 | 26.5 ±2.2 | 20 | 31.5 | 0.66 | 2.38 | 2.12 | 10.6 | 5.9 | 0.26 |
| H7 | 27.2 ± 4.1 | 22 | 32 | 29 ± 2.5 | 23.5 | 32 | 0.73 | 2.61 | 2.32 | 11.6 | 6.5 | 0.29 |
| Min | 9.4 | 1 | 15 | 11 | 7 | 14 | 0.27 | 0.99 | 0.88 | 4.4 | 2.5 | 0.11 |
| Max | 32 | 23 | 56 | 32.5 | 26 | 49.5 | 0.81 | 2.92 | 2.60 | 13 | 7.3 | 0.32 |
| Av.±SD | 23.5±7.2 | 17.1±7.6 | 35.4±13.2 | 23.8± 6.9 | 19.6±6 | 31.7±10.9 | 0.59±0.17 | 2.1±2.9 | 1.9±2.6 | 9.5±2.7 | 5.4±1.5 | 0.23±0.07 |

**Table 3.** Minimum, maximum and average radon concentration measured by Corentium and RAD7 detector and dose assessment of radon and its progeny AED, $D_E$, $D_s$, $D_L$, EEC, PAE and RDE of the selected dwellings in summer season.

| Sample codes | RC measured by Corentium | | | RC measured by RAD7 | | | Dose assessment of radon and its progeny | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Av. RC ± SD Bq m$^{-3}$ | Min RC Bq m$^{-3}$ | Max RC Bq m$^{-3}$ | Av. RC ± SD Bq m$^{-3}$ | Min RC Bq m$^{-3}$ | Max RC Bq m$^{-3}$ | AED mSv y$^{-1}$ | $D_s$ mSv y$^{-1}$ x10$^{-9}$ | $D_L$ mSv y$^{-1}$ x10$^{-8}$ | EEC Bq m$^{-3}$ | PAE J m$^{-3}$ x10$^{-8}$ | DRE mSv y$^{-1}$ |
| H1 | 20 ± 1 | 12 | 28 | 20.2 ± 1.4 | 18 | 22 | 0.51 | 1.81 | 1.61 | 8.08 | 4.5 | 0.2 |
| H2 | 13 ± 0.8 | 5 | 19 | 14 ± 1.1 | 3 | 18 | 0.35 | 1.26 | 1.12 | 5.6 | 3.1 | 0.14 |
| H3 | 21 ± 1.2 | 9 | 29 | 22 ± 1.7 | 11 | 29.5 | 0.55 | 1.98 | 1.76 | 8.8 | 4.9 | 0.22 |
| H4 | 7 ± 1.5 | 1 | 13 | 5 ± 0.8 | 2 | 9 | 0.12 | 4.5 | 4 | 2 | 1.1 | 0.05 |
| H5 | 13 ± 0.9 | 5 | 17 | 12 ± 2.1 | 7 | 16 | 0.3 | 1.08 | 9.6 | 4.8 | 2.7 | 0.12 |
| H6 | 12 ± 1.1 | 4 | 16 | 14 ± 2.2 | 11 | 19 | 0.35 | 1.26 | 1.12 | 5.6 | 3.2 | 0.14 |
| H7 | 18 ± 1.5 | 14 | 25 | 17.8 ± 1.8 | 15 | 22 | 0.44 | 1.6 | 1.42 | 7.12 | 4 | 0.17 |
| Min | 7 | 1 | 13 | 5 | 2 | 9 | 0.12 | 4.5 | 4 | 2 | 1.1 | 0.05 |
| Max | 21 | 14 | 29 | 22 | 18 | 29.5 | 0.55 | 1.98 | 1.76 | 8.8 | 4.9 | 0.22 |
| Av.±SD | 15±5.1 | 7.1±4.7 | 21±6.3 | 15±5.7 | 9.5±5.9 | 19.3±6.3 | 0.37±0.14 | 1.35±1.18 | 1.2± 3 | 6±2.3 | 3.8± 1.3 | 0.15±0.06 |



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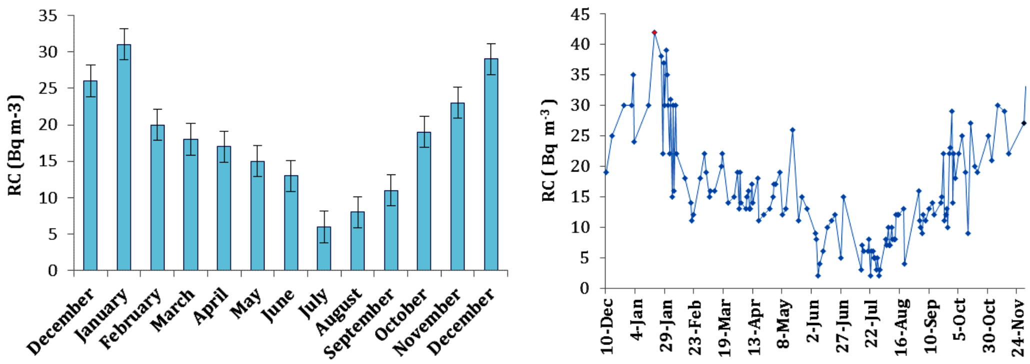


**Figure 2. (A)** Monthly **(B)** daily, radon concentration time series in dwelling H6, from December 2019 - December 2020.

**Table 4.** Measurements of RC, Humidity, Temperature and Wind speed at closed building in different winter dates (No ventilation).

| Dates | RC (Bq m$^{-3}$) | Humidity % | T ($^{o}$C ) | Wind speed (m s$^{-1}$) |
|---|---|---|---|---|
| 2-Jan | 15 | 85 | 11 | 4.2 |
| 9-Jun | 19 | 70 | 8 | 3.1 |
| 20-Jun | 20 | 90 | 7 | 5.3 |
| 8-Feb. | 20 | 92 | 5 | 5.3 |
| 9-Feb. | 11 | 76 | -2 | 2.5 |
| 11-Feb. | 11.4 | 70 | -4 | 1.9 |
| 26-Feb. | 17.5 | 65.7 | 10.5 | 1.8 |
| 27-Feb. | 17.5 | 67 | 11.4 | 1.5 |
| 28-Feb. | 29 | 67.6 | 11.5 | 1.4 |
| 29-Feb. | 20 | 72 | 12 | 2.5 |
| 2-March | 19 | 83 | 10 | 1.7 |
| 3-March | 19 | 65 | 10 | 1.7 |
| 5-March | 16 | 74.1625 | 6.8 | 2.0 |
| 6-March | 23 | 55.4 | 14 | 3.6 |

**Table 5.** Some studies about the indoor radon investigation around the world

| Locations | $^{222}$Rn concentration (Bq m$^{-3}$) | AED (mSv y$^{-1}$) | References |
|---|---|---|---|
| Iraq- Duhok city | 19 | 0.48 | Present study |
| Iraq-Erbil city | 44 | 1.3 | (13) |
| Iraq – Baghdad city | 10.67 | - | (23) |
| Iraq – Mosul city | 62.36 | 1.57 | (24) |
| Iran-Qom city | 95.87 | - | (6) |
| Iran Zanjan city | 56.95 | < 1.094 | (25) |
| Turkey | 57 | - | (26) |
| Egypt- Alexandria city | 44 | 0.75 | (27) |
| Saudi Arabia- Al-Kharj City | 19.4 | 0.49 | (28) |
| India | 35.6 | - | (29) |
| Thailand | 53 | 2.1 | (30) |
| Poland- Podlasie Province | 45 in city 111 in rural areas | 1.1 in city 2.8 in rural area | (31) |

## DISCUSSION

In this study the average level of indoor radon concentration in Duhok city in both seasons was 19 ± 6.1 Bq m$^{-3}$. According to the previous region studies, the results of this study are broadly in agreement with the research carried out in other Iraq cities [13 - 23 - 24]. The average rate of indoor radon in present study is higher than that study done in Iraq – Baghdad city [23] while it is lower than study done in Iraq-Erbil and Mosul cities and other foreign studies presented in table 5. Anyhow, the results come back identical and lower than WHO [24] and ICRP recommendation [19].

The results show that the family house living in dwelling H5 tends to show higher average RC in summer and H3 in winter than other dwellings. The geological environments at all measurement dwellings approximately are similar. So, this might be due to the nature of the building materials utilized or the household living styles [6]. Furthermore, the highest value of AED and DRE were recorded in winter in dwelling H5 where maximum value of radon concentration is obtained in it because there is a direct relationship between level of radon and its exposure [17]. According to t-test of two groups (summer and winter season) indoor radon concentration is statistically significant difference ($p<0.05$). What has been found in this study are consistent with those of many other studies that have been done on this topic [4, 9, 11]. This is because, indoor radon concentration levels strongly depend on ventilation conditions in summer most doors and windows are opened. Radon gas can easily move out and does not accumulate inside the building; the indoor radon level goes down in summer season in comparison to winter season [9].

The outcomes show that the lowest value of RC is recorded in H4 by both detectors in both seasons; this dwelling is the one of the oldest designed houses in Duhok. It is an open house, which leads to higher ventilation. T-test show that there is no significant different ($p > 0.05$) between RC measured by Corentium monitor and RAD7 detector. Therefore, these results assess the strong degree of agreement between using both detectors.

According to Salih & Mohammed (2014) [9] indoor radon concentration in northern climate is typically higher during winter and has lower value during summer seasons. In the present study (figure 2A) same trend is observed, the highest level of RC in January (winter) and the lower RC level in July (summer). Particularly evident are the annual cycles of air temperature and ventilation since the weather in Duhok is influenced by Interior Mediterranean climate [15], the hottest month is July which most of



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the day time fans and air conditionings are operated with most windows being kept open, while, the coldest month is January where the temperature could be even less than 0°C at night. So, in this coldest month, households are generally keep their doors and windows closed as mentioned previously while in spring and autumn natural ventilation are used this result was in good agreement with investigation has been reported by other researchers (32 - 33).

## CONCLUSION

Radon concentrations were measured and annual effective dose were estimated in Duhok dwellings. Indoor radon concentrations vary with the seasonal variation and it is evident that the ventilation and metrological parameter has significant effect on the reduction of radon concentration. Radon gas levels have been found higher during winter than summer season; several factors can affect its level. The risk of the dose exposure to radon in the study locations are below the recommended working level of WHO and ICRP agencies. Finally as recommendation, proper regulatory standards like natural and forced ventilation should be implemented to the design of dwellings in order to make them more suitable and safer.

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