Assessment of Radon Exposure in Erbil Drinking Water Resources

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\textbf{ARTICLE INFO}

\textbf{Article History:}
Received: 01/06/2017
Accepted: 05/08/2017
Published: 20/12/2017

\textbf{Keywords:}
Radon concentration; Drinking water; Total annual effective dose, CR-39 nuclear track detector.

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\textbf{ABSTRACT}

In present study radon activity concentration in drinking water samples were carried out from Erbil-governorate (Kurdistan region-Iraq) by using a permeable cup provided with CR-39 alpha nuclear track detector as a passive method. The results show that the range of radon (\textsuperscript{222}Rn) concentration values vary from (0.081±0.002 to 14.742±0.262) Bq/l. The obtained values in this study are below the maximum contamination level (MCL) 11.1 Bq/l as recommended by US-EPA, except sample no. (S12), from Barsaleen region. The total annual effective dose due to ingestion and inhalation of radon from drinking water samples for adults, children and infants were determined. The maximum values found in (S12)were (0.09489±0.0007, 0.10920±0.0009 and 0.233±0.0024) mSv/y respectively, while the minimum values recorded in the (S20) from Koyea were (0.00043±0.0001, 0.00049±0.0001 and 0.001±0.0004) mSv/y respectively. The results of this study well indicate that 32\% and 4\%, from the total annual effective doses in well and spring drinking water samples which intake by infants and children respectively in Erbil are higher than the maximum contaminate levels of 0.1mSv/y proposed in the WHO for the intake of radionuclide in drinking water.
1. INTRODUCTION

Radiation is a natural part of the environment in which we live in. All people are exposed to naturally occurring radioactivity in soil, water, air and food. The largest fraction of the natural radiation exposure we receive comes from a radioactive gas, radon ($^{222}$Rn) (Rafat M. A., 2013). Radon is the decay product of radium ($^{226}$Ra) in the naturally occurring uranium ($^{238}$U) series. As an inert gas, radon can move freely through the soil and water from its source to a distance which is determined by many factors such as rate of diffusion, effective permeability of the medium and its own half-life. Being a natural alpha emitter, radon can be detected by an alpha sensitive detector. It has been established that radon is a causative agent of lung cancer when present in higher concentrations (V. E. Archer and et.al, 1976). The World Health Organization (WHO) suggests that radon causes up to 15% of lung cancers worldwide (R. L. Fleischer, 1982). In 2012, Environmental Protection Agency (EPA) proposed a Maximum Contaminant Level (MCL) for radon of 11.1Bq/L (about 300 PCi/L) in drinking water (R. L. Fleischer, 1980). Monitoring drinking water quality is an important aspect of public health studies. Radon estimation is one among the public health studies, as it describes the extent of population exposure to radiation as well as the influencing sources water. Hence, an attempt has been made in this present research work for estimation of radon in drinking water resources from Erbil-Governorate –Iraqi Kurdistan region using CR-39 nuclear track detectors.

2. Materials and Methods

2.1 Geographical Location

Hawler (Erbil) is the capital of the Iraqi Kurdistan Region, located between latitudes 35° 40′ and 36° 30′ N, and longitudes 43° 20′ and 44° 20′ E as shown in Fig. (1).

![Figure 1. The location of Erbil governorate in Iraqi map.](image)

The area is bordered by two major rivers, the upper Zab River in the North West and the lower Zab River in the southeast side. Precipitation, snow melting in winter and spring sources in the summer season are the main sources of these two rivers. The two rivers flow at a much lower elevation than the general topographic level of the area, thus the ground water is the most important source for irrigation and drinking purposes (R.H. Haddad and P.B. Smoor, 1973) and (Z. Stevanovic, and A. Iurkiewicz, 2009).

In the present work, twenty-one types of widely-used drinking bottled water samples which are available in the market of Iraqi Kurdistan Region were collected and analyzed by using passive (SSNTDs) and active (RAD-H$_2$O) methods. For each type about 2 liters of bottled water, have been taken. Pieces of CR-39 track detectors (1×1
cm² area) were fixed under the cover of plastic Can, which contain the water samples.

2.2 Field work preparation

The sample of the drinking water in Erbil governorate was collected according to two factors, one of them is the geological difference formation and the second is population density in the area of study. Erbil possesses a population of approximately 1.9 million, 1.007 million of which live in the capital. Erbil is the fourth largest city in Iraq after Baghdad, Basra, and Mosul. According to the last survey by the NCCI in 2012 [8], Erbil’s population distribution by district is as follows, 11.1% in Shaqlawa, 2.7% in Choman, 3.7% in Makhmur, 13.4% in Soran, 6% in Koisnjaq, 3.7% in Mergasur, and 59.4% in Erbil. The geographic distribution in rural and urban areas is 24% and 76% respectively. The total area of Erbil is 14,417 Km². (3.5% of Iraq). Water samples collected from the surface, spring and ground wells were used as drinking water. The sample's position was fixed on the map by using GPS systems as shown in Table (1) and their locations are shown in Fig (2).

2.3 Water sampling and sample preparation

Twenty-five water samples from different water resources, twelve from underground wells, five from spring source and eight of surface sources were collected from the study areas in Erbil Governorate and analyzed as shown in Table (1). Samples were collected in (1.5) liters capacity polyethylene containers, saved in cool box and transferred to our laboratory in Erbil City and kept in a room temperature for preservation. About 250mL, were prepared for radon activity concentration measurement by using a permeable cup provide with CR-39 plastic track detectors.

2.4 Radon Activity Concentration Measurement

A closed permeable cup of 3.55 cm in radius and 8 cm in height was provided with CR-39 nuclear track detectors and a sponge filter, was calibrated previously (Samal, S.F, 2011) and has been used as a passive method for measuring radon activity concentration in water samples.
This cup is covered by a cover containing many holes for air exchange, the holes are covered by a piece of sponge as a diffusion barrier with a thickness of (0.5 cm) as shown in Figures (3) that discriminates short-lived thoron by delaying the entry of gases into the cup, and blocks the entry of radon progeny and to diminish the evaporation of the water samples.

In order to find the relationship between the track density recorded by a CR-39 alpha track detector and the emitted radon from water samples, we fixed the permeable cup tightly on the water container which is of the same dimensions in diameter and length with the permeable cup, (250) mL of water sample from each source were placed in a container and sealed by different techniques for 60 days so as to attain the equilibrium and although to collect a good quantity of radon gas. Then the detectors can record alpha particles resulting from the decay of radon. Then the exposed detectors were etched in 6.25 NaOH solution at 70°C for 6 hours using a constant temperature bath [9]. The tracks were counted using an optical microscope at 40X magnification. A total of 20 fields to a maximum 22 fields of the detector were counted. The number of alpha-particle tracks per field is averaged over the number of fields counted after subtracting the background (which equal to 127 tracks/cm²). The standard deviation of the average was obtained and the track density (tracks/cm²) on each detector was calculated, subsequently the radon activity concentration in each water samples have been determined by using (Durrani. S.A., 1997)

\[ C_{Rn} = \frac{\rho}{K \cdot T_{eff}} \]  

where \( C_{Rn} \) is radon activity concentration in the air volume of cup which is removed from water samples, \( \rho \) is track density and \( K \) is calibration factor (0.141 Tracks.cm⁻² d⁻¹ per Bq.m⁻³) (Samal, S.F, 2011).

Where \( T_{eff} \) is the effective time (54.47 days), which is the correction time needed only for closed system and can be calculated by (Duggala. V. and et.al 2012)

\[ T_{eff} = T - \frac{1}{\lambda} \left(1 - e^{-\lambda t}\right) \]  

where \( T \) is the exposure time (60 days) and \( \lambda = 0.181 \) days⁻¹

The radon concentration in the water samples can be measured by (Somogyi. Gand L.Lenart, 1986).

\[ C_{RnW} = C_{Rn} \cdot \alpha \]  

where \( \alpha \) is the radon partition coefficient

\[ \alpha = \frac{1}{0.1057 + 0.405 \exp(-0.05t)} \]  

where \( t \) is the lab water temperature (20±2) °C
2.5 Evaluation of Mean Annual Effective Radon Dose

The radiation dose received from radon present in drinking water can be divided into two components, namely, (a) the dose received from radon ingested and (b) the dose received from radon inhaled. In case of ingestion, radon and its progenies present in the drinking water can impart a radiation dose mainly to the stomach. However, radon gas present in the drinking water can also escape into the indoor air during showering and other domestic uses and can cause a significant increase in the risk of lung cancer due to the radon inhaled.

The annual effective dose (µSv/y) due to ingestion of the drinking water was calculated by taking into account the activity concentration of radon (Bq/l), the dose conversion factor DCF (Sv/Bq) and the annual water consumption (l/y) according to equation (Ali, N, and et.al, 2010).

\[ A.E.D_{\text{ing}} = C_{\text{RnW}} \times C_{W} \times DCF \]  
(5)

where \( C_{\text{RnW}} \) is the concentration of radon in drinking water, \( C_{W} \) is the annual water intake equal to (0.6, 0.8, 1.3) l/d for (infant, children, adult) respectively and DCF is equal to (7×10\(^{-8}\), 2×10\(^{-8}\), 1×10\(^{-8}\)) Sv/Bq for (infant, children, adult) respectively (Ndontchueng, M. and et.al, 2013) and (Nasir, T and Shah. M, 2012).

The annual effect dose due to inhalation of the drinking water was calculated by using the following equation:

\[ A.E.D_{\text{inh}} = C_{\text{RnW}} \times R \times F \times O \times DCF \]  
(6)

\( R \) is the ratio of radon in air to the radon in water (10\(^{-4}\)), \( F \) is the equilibrium factor between radon and its progeny (0.4), \( O \) is the average indoor occupancy time per individual (7,000 h. y\(^{-1}\)) and DCF is the dose conversion factor for radon exposure [9 nSv/(Bq h m\(^{-3}\))] (Khattak, N and et.al, 2011).

3. Results and Discussion

The results for radon activity concentrations in water samples belong to the area of the Erbil governorate by this method was reported in Table (1). The values varied from (0.081±0.002 to 14.742±0.262) Bq/l. The higher and lower concentrations values were recorded at Barsalin (S12) and Koya (S20) which were (14.742±0.262 and 0.081±0.002) Bq/l respectively. The histogram where shown in Fig. (5).

![Figure 5. Histogram of radon activity concentration in drinking water samples.](image)

It is clear that the radon concentration in water samples changed from location to another. This variation may be due to the type of water, the geological formation and the difference of geochemical distribution of areas under the study (Oliveira, J. and et.al. (2001)).
Table 2. The mean value of radon activity concentrations in the drinking water samples ($C_{Rn,W}$).

| Sample Code | Location       | $C_{Rn,W}$ Bq/l±SD |
|-------------|----------------|---------------------|
| S1          | Gawara         | 4.718±0.123         |
| S2          | Sultan Abdulla | 0.616±0.352         |
| S3          | Debaga         | 10.424±0.105        |
| S4          | Banaman        | 1.433±0.129         |
| S5          | Jondian        | 2.070±0.017         |
| S6          | Hojran         | 9.542±0.220         |
| S7          | Sarmedan       | 4.291±0.066         |
| S8          | SH. Mamodian   | 9.448±0.407         |
| S9          | Alana          | 2.129±0.252         |
| S10         | Bekhal         | 0.092±0.016         |
| S11         | Rawndez        | 0.120±0.019         |
| **S12**     | **Barsaleen**  | **14.742±0.262**    |
| S13         | Hafaze         | 0.142±0.051         |
| S14         | Choman         | 0.188±0.010         |
| S15         | SH. Balakan    | 1.711±0.060         |
| S16         | Rezan          | 0.377±0.088         |
| S17         | Sedacan (M)    | 0.567±0.207         |
| S18         | Peran          | 1.166±0.105         |
| S19         | Sedacan (Well) | 7.171±0.015         |
| **S20**     | **Koyea**      | **0.081±0.002**     |
| S21         | Krosh          | 6.445±1.150         |
| S22         | Bnaslawa       | 7.802±0.302         |
| S23         | Engineering college (Tank) | 3.875±0.100 |
| S24         | Engineering (well) | 6.911±0.082 |
| S25         | Erbil Efraz    | 0.103±0.020         |

*mean value of three measurement for each water sample.

On the other hand, Table (2) shows that the rate of radon activity concentration in the sample (S24) is higher than that of the sample (S23), which was taken from the well and tank and both were originate from the same resource. This indicates that the radon activity in well is higher than that of tank. Thus, before it is used in public networks, it is necessary to use drinking water from groundwater or wells after being stored for the purpose of purification and treatment. When water storage before its usage, will reduce the concentration of radon and its progenies.

Tables (3), (4) and (5) show that the minimum average value of radon concentration was found in surface water (S20) while the maximum average value was found in well water (S12). It is clear from Tables (3, 4 and 5) that the average radon concentration in the well is higher than spring and surface waters. This is because the ground water may contain high amounts of natural radioactive isotopes mainly associated with uranium and thorium-rich soils and rocks, while surface water usually contains lower amounts of radon than spring and ground waters (Duenas. C and et.al,1999). The reason of high radon concentration in the water samples (S12) of the Barsaleen may be due to its site, which is located in uranium rich black shell bedrocks. This fact also reported by the refs. (Asad. H., 2004). Also, the high radon concentration in water samples (S3,S8&S6) of Debaga, SH. Mamodian and Hojran may be due to foundation of petroleum in that place which is an indicator of uranium presence. These uranium rich geological formations may have played a major role in contributing high radon contents to the water sources within the region. Since there is no specific national regulation of radioactivity concentration in drinking water in the Iraqi Kurdistan region, the results have been compared with the maximum contaminant level (11.1) Bq/l for radon in public drinking water, suggested by the US-EPA (Mustapha. A.O, 2002). The
obtained results are listed in Tables (3,4-5) for radon concentration values in surface, spring and well water samples which are below this normal level, except for Barsaleen (S12). The range measurement of radon activity concentration in surface, spring and drilling well drinking water samples in this study were found to be in agreement with those reported by other references as shown in Table (6).

Table 3. The mean value of radon activity concentrations in Erbil governorate surface water samples.

| S. No | Sample Name  | $C_{Rnw}$ Bq/l ± SD |
|-------|--------------|---------------------|
| S2    | Sultan Abdulla | 0.616±0.352          |
| S10   | Bekhal        | 0.092±0.016          |
| S11   | Rawndez       | 0.120±0.019          |
| S13   | Hafize        | 0.142±0.051          |
| S14   | Choman        | 0.188±0.010          |
| S16   | Rezan         | 0.377±0.088          |
| S20   | Koyea         | 0.081±0.002          |
| S25   | Efraz         | 0.103±0.020          |

Table 4. The mean value of radon activity concentrations in Erbil governorate spring water samples.

| S. No | Sample Name  | $C_{Rnw}$ Bq/l ± SD |
|-------|--------------|---------------------|
| S5    | Jondian      | 2.070±0.017         |
| S9    | Alana        | 2.129±0.252         |
| S15   | SH. Balakan  | 1.711±0.060         |
| S17   | Sedacan (M)  | 0.567±0.207         |
| S18   | Peran        | 1.166±0.105         |

Table (6, col. 4) represent the results of the annual effective dose due to inhalation of radon in drinking water samples using eq. (6).

Table 5. The mean values of radon activity concentrations in Erbil governorate well water samples.

| S. No | Sample Name       | $C_{Rnw}$ Bq/l ± S.D |
|-------|--------------------|----------------------|
| S1    | Gawara             | 4.718±0.123          |
| S3    | Debega             | 10.424±0.105         |
| S4    | **Banaman**        | **1.433±0.129**      |
| S6    | Hojran             | 9.452±0.220          |
| S7    | Sarmedan           | 4.291±0.066          |
| S8    | SH. Mamodian       | 9.448±0.407          |
| S12   | **Barsaleen**      | **14.742±0.262**     |
| S19   | Sedacan (well)     | 7.171±0.015          |
| S21   | Krosh              | 6.445±1.150          |
| S22   | Bnaslawa           | 7.802±0.302          |
| S23   | Engineering college (Tank) | 3.875±0.100 |
| S24   | Engineering college (well) | 6.911±0.082 |

It is found that the values are the same for all age groups. Moreover, Table (7) shows the total annual effective dose due to ingestion and inhalation of radon from drinking water samples for infants, children and adults. The maximum values found in (S12) were (0.09489±0.0007, 0.10920±0.0009 and 0.233±0.0024) mSv/y respectively, while the minimum values recorded in the (S20) were (0.00043±0.0001, 0.00049±0.0001 and 0.001±0.0004) mSv/y respectively. Children and infant show increased vulnerability due to a combination of changes in dose conversion factor and water intake with age as shown in Fig. (6).

The results of this study indicate that 32% and 4% of the total annual effective doses intake by infants and children in Erbil are higher than the maximum contaminant...
levels of 0.1mSv/y proposed in the WHO for intake of radionuclide in drinking water (Moldovan, M and et.al, 2014).

The mean total annual effective dose due to drinking water samples in this study was found to be in a good agreement with those values reported in other references as shown in Table (11).

![Figure 6. Annual effective dose due to ingestion of radon in drinking water samples for difference groups age as a function of their radon activity concentration.](image)

**Table 1.** Geographical position of sampling location in Erbil governorate.

| Sample Code | Name of the site       | Location                          | Elevation/feet |
|-------------|------------------------|-----------------------------------|---------------|
|             |                        | Latitudes                        | Longitudes    |
| S1          | Gawara                 | 35.775449°                       | 43.581864°    | 892 |
| S2          | Sultan Abdulla         | 35.775449°                       | 43.581864°    | 865 |
| S3          | Debaga                 | 35.775435°                       | 43.581864°    | 1208 |
| S4          | Banaman                | 36.355307°                       | 44.209800°    | 2488 |
| S5          | Jondian                | 36.605378°                       | 44.489360°    | 7133 |
| S6          | Hojran                 | 36.539436°                       | 44.450000°    | 3695 |
| S7          | Sarmedan               | 36.398954°                       | 44.328865°    | 3223 |
| S8          | SH. Mamodian           | 36.460740°                       | 44.422643°    | 2739 |
| S9          | Alana                  | 36.460740°                       | 44.422643°    | 2644 |
| S10         | Bekhal                 | 36.539294°                       | 44.440755°    | 2357 |
| S11         | Rawndez                | 36.605378°                       | 44.489360°    | 2143 |
| S12         | Barsaleen              | 36.623705°                       | 44.533976°    | 3010 |
| S13         | Hafaze                 | 36.626441°                       | 44.660388°    | 2397 |
| S14         | Choman                 | 36.600873°                       | 44.716670°    | 4701 |
| S15         | SH. Balakan            | 36.628694°                       | 44.883742°    | 5755 |
| S16         | Rezan                  | 36.675857°                       | 45.043856°    | 1473 |
| S17         | Sedacan (M)            | 36.852741°                       | 44.139241°    | 3423 |
| S18         | Peran                  | 36.802888°                       | 44.625242°    | 2571 |
| S19         | Sedacan (ber)          | 36.905191°                       | 44.358258°    | 2823 |
| S20         | Koyea                  | 36.045738°                       | 44.740433°    | 2167 |
| S21         | Krosh                  | 36.802261°                       | 44.623064°    | 2363 |
| S22         | Bnaslawa               | 36.165415°                       | 44.622042°    | 1701 |
| S23         | Engineering College tank | 36.161203°   | 44.122362°    | 1366 |
| S24         | Engineering College well | 36.153344°  | 44.058379°    | 1366 |
| S25         | Efraz Erbil            | 36.118158°                       | 43.951037°    | 1349 |
Table 6. Mean annual effective dose due to ingestion and inhalation in (µSv/y) for various ages.

| S.No | Adult         | Children       | Infants        | Annual effect due to Inhalation for All ages µSv/y ± S.D |
|------|---------------|----------------|----------------|--------------------------------------------------------|
| S1   | 21.88 ± 1.942 | 26.93 ± 2.390  | 70.69 ± 6.274  | 11.62 ± 0.288                                          |
| S2   | 1.25 ± 0.399  | 1.53 ± 0.491   | 4.03 ± 1.289   | 0.66 ± 0.827                                          |
| S3   | 48.80 ± 0.664 | 60.07 ± 0.818  | 157.68 ± 2.146 | 25.92 ± 0.246                                          |
| S4   | 5.18 ± 0.272  | 6.79 ± 0.335   | 16.74 ± 0.880  | 2.75 ± 0.303                                          |
| S5   | 13.65 ± 4.524 | 16.80 ± 5.568  | 44.09 ± 14.617 | 7.24 ± 0.414                                          |
| S6   | 46.79 ± 4.886 | 57.59 ± 6.014  | 151.19 ± 15.787| 24.85 ± 0.517                                          |
| S7   | 18.77 ± 1.850 | 23.10 ± 2.278  | 60.64 ± 5.979  | 9.69 ± 0.155                                          |
| S8   | 41.73 ± 7.774 | 51.36 ± 9.569  | 134.82 ± 25.118| 22.16 ± 0.955                                          |
| S9   | 11.49 ± 0.287 | 14.14 ± 0.354  | 37.13 ± 0.929  | 6.10 ± 0.591                                          |
| S10  | 0.46 ± 0.202  | 0.57 ± 0.249   | 1.51 ± 0.654   | 0.24 ± 0.038                                          |
| S11  | 0.88 ± 1.037  | 1.08 ± 1.278   | 2.83 ± 3.353   | 0.46 ± 0.044                                          |

**S12 61.97 ± 0.735 76.28 ± 0.902 200.24 ± 2.368 32.91 ± 0.616**

| S13  | 1.12 ± 0.653  | 1.38 ± 0.804  | 3.63 ± 2.111  | 0.59 ± 0.121                                          |
| S14  | 0.79 ± 0.825  | 0.97 ± 1.016  | 2.55 ± 2.668  | 0.42 ± 0.022                                          |
| S15  | 7.66 ± 1.260  | 9.43 ± 1.552  | 24.75 ± 4.073 | 4.07 ± 0.141                                          |
| S16  | 1.90 ± 0.228  | 2.34 ± 0.281  | 6.14 ± 0.737  | 1.01 ± 0.028                                          |
| S17  | 2.31 ± 0.220  | 2.85 ± 0.271  | 7.48 ± 0.713  | 1.23 ± 0.487                                          |
| S18  | 5.46 ± 0.614  | 6.72 ± 0.756  | 17.64 ± 1.985 | 2.90 ± 0.247                                          |
| S19  | 31.36 ± 1.535 | 38.59 ± 1.890 | 101.31 ± 4.962| 16.65 ± 0.036                                          |

**S20 0.27 ± 0.120 0.34 ± 0.148 0.39 ± 0.189 0.15 ± 0.005**

| S21  | 27.77 ± 3.077 | 34.18 ± 3.787 | 89.73 ± 9.941 | 14.75 ± 0.701                                          |
| S22  | 32.99 ± 6.487 | 40.61 ± 7.984 | 106.60 ± 20.95 | 17.52 ± 0.708                                          |
| S23  | 16.74 ± 1.735 | 20.60 ± 2.136 | 54.09 ± 5.606 | 8.89 ± 0.234                                          |
| S24  | 33.12 ± 3.835 | 40.76 ± 4.721 | 107.01 ± 12.393| 17.59 ± 0.192                                          |

**S25 0.69 ± 0.301 0.84 ± 0.371 2.22 ± 0.974 0.60 ± 0.047**

Table 7. Total Annual effective dose due to ingestion and annihilation for various ages (mSv/y).

| S.No | Total annual effect dose (mSv/y) ±S.D |
|------|--------------------------------------|
| Adult| Children                             | Infant                              |
| S1   | 0.0335 ± 0.0019                      | 0.0385 ± 0.0024                     | 0.082 ± 0.0063                      |
| S2   | 0.0019 ± 0.0004                      | 0.0022 ± 0.0005                     | 0.005 ± 0.0013                      |
| S3   | 0.0747 ± 0.0007                      | 0.0859 ± 0.0008                     | 0.18 ± 0.0021                       |
| S4   | 0.0079 ± 0.0003                      | 0.0091 ± 0.0003                     | 0.019 ± 0.0009                      |
| S5   | 0.0209 ± 0.0045                      | 0.0240 ± 0.0056                     | 0.051 ± 0.014                       |
| S6   | 0.0716 ± 0.0049                      | 0.0824 ± 0.0060                     | 0.176 ± 0.015                       |
| S7   | 0.0287 ± 0.0019                      | 0.0330 ± 0.0023                     | 0.071 ± 0.0060                      |
| S8   | 0.0639 ± 0.0078                      | 0.0735 ± 0.0096                     | 0.157 ± 0.025                       |
| S9   | 0.0176 ± 0.0003                      | 0.0205 ± 0.0004                     | 0.043 ± 0.0009                      |
| S10  | 0.0007 ± 0.0002                      | 0.0008 ± 0.0002                     | 0.002 ± 0.0007                      |
| S11  | 0.0013 ± 0.0010                      | 0.0015 ± 0.0013                     | 0.003 ± 0.003                       |
| S12  | 0.0949 ± 0.0007                      | 0.1092 ± 0.0009                     | 0.233 ± 0.0024                      |
| S13  | 0.0017 ± 0.0007                      | 0.0019 ± 0.0008                     | 0.004 ± 0.0021                      |
| S14  | 0.0012 ± 0.0008                      | 0.0013 ± 0.0010                     | 0.003 ± 0.0027                      |
| S15  | 0.0117 ± 0.0013                      | 0.0135 ± 0.0016                     | 0.029 ± 0.0041                      |
| S16  | 0.0029 ± 0.0002                      | 0.0033 ± 0.0003                     | 0.007 ± 0.0007                      |
| S17  | 0.0035 ± 0.0002                      | 0.0048 ± 0.0003                     | 0.009 ± 0.0007                      |
| S18  | 0.0083 ± 0.0006                      | 0.0096 ± 0.0008                     | 0.021 ± 0.0020                      |
| S19  | 0.0480 ± 0.0015                      | 0.0552 ± 0.0019                     | 0.118 ± 0.0050                      |
Table 8. The mean total annual effective dose for adult of water samples in worldwide and present study.

| Country           | The mean total annual effective dose (mSv/y) | References                  |
|-------------------|---------------------------------------------|-----------------------------|
| Coonoor, India    | 0.0102                                      | (Selvasekarapandian, S, 2002) |
| Varahi, India     | 0.00755                                     | (Somashekar. And et.al, 2010). |
| Markandeya, India | 0.03393                                     | (Somashekar. And et.al, 2010). |
| Peshawar, Pakistan| 0.02403                                     | (Khattak, N, 2011)            |
| Turkey            | 0.00587                                     | (Oner. F, and et.al 2009).    |
| Ghana             | 0.0592                                      | (Darko. E.,and et.al 2010).   |
| China             | 0.085                                       | (Xinwei. L, 2006).           |
| Poland            | 0.0171                                      | (Alabdua. A.I., (1999)).     |
| Iraq (Erbil)      | 0.0266                                      | Present study                |

4-Conclusions

In this research, the following points have been concluded:

1- The well water samples are characterized by the highest average of radon levels, while the surface water is characterized by the lowest one. The overall average of radon levels in Erbil public drinking water samples is about 36.8% of the internationally acceptable radon level in drinking water.

2- The results of this study indicate that 32% and 4% of the total annual effective doses intake by infants and children in Erbil are higher than the maximum contaminant levels of 0.1mSv/y proposed in the WHO for intake of radionuclide in drinking water.

3- The obtained values show that surface water in Erbil governorate is safe for drinking without exceeding the proposed radioactivity criterion level.

Reference:

Aasad. H. I, (2004). “Measurement of Radon Activity concentration in Iraqi Kurdistan Soil by Using CR-39 Nuclear Track Detectors “,MSc. Thesis, University of Salahaddin, Iraqi-Kurdistan.

Alabdua. A.I, (1999). “Occurrence of radon in the central region groundwater of Saudi Arabia”, J. Environ. Radioactivity, Vol.(44), pp. 85-95.

Ali N., Khan. E. U, Akhter. P, Khan. F., Waheed. A, (2010). “Estimation of mean annual effective dose through radon concentration in the water and indoor air of Islamabad and Murree”, J.Radiat. Prot. Dosim. Vol.(141), No.(2), pp. 183-191.

Archer. V. E, Gillam J. D. and Wagoner. J. K, (1976) .“Respiratory Disease Mortality among Uranium Miners”, Ann. NY Acad. Sci.; Vol. (271), pp. 280-293.

Darko. E.O, Adukpo O. K, Fletcher. J. J, Awudu A. R., and Otoo, F , (2010). “Preliminary studies on 222Rn concentration in ground water from selected areas of the Accra metropolis in Ghana”, J. Radioanal. Nucl. Ch.,Vol.(283), pp.507-512.

Duenas. C, Fernandez. M, Carretero. C, Liger. J, Canete. E, (1999). „226Ra and 222Rn concentrations and doses in bottled waters in Spain”, J. Environ. Radioa, Vol.(45), pp. 283–290.

Duggala.V, Rani. A and Mehra. R, (2012) “In situ measurements of radon levels in groundwater in Northern Rajasthan, India”, J. Advances in Applied Science Research, Vol.(6), No.(3), pp. 3825-3830.

Durrani. S.A and Ilic . R, (1997), “Radon Measurements by Etched Track Detectors”, first edition.

Fleischer. R. L, (1980) “Isotopic disequilibrium of uranium: alpha-recoil damage and preferential solution effects”, J.Science, Vol( 207), No.( 4434), pp. 979-981.
Fleischer, R. L. (1982). “Alpha-recoil damage and solution effects in minerals: uranium isotopic disequilibrium and radon release”, J. Geochim. Cosmochim. Acta, Vol.(46), pp.2191-2201.

Haddad, R.H. and Smoor, P.B. (1973). “Groundwater survey of Arbil project area”, IARNR Tech. Bull, No.(50), Baghdad.

Khattak, N. U., Khan, M. A., Shah, M. T. and Javed, M. W. (2011). “Radon concentration in drinking water sources of the Main Campus of the University of Peshawar and surrounding areas, Khyber Pakhtunkhwa, Pakistan”, J. Radioanal. Nucl. Chem, Vol.(290), pp.493-505.

Moldovan, M, Nit. D. C, Dinu, A.C, Dicu, T, Bris, N. B and Cosma, C (2014). “Radon concentration in drinking water and supplementary exposure in Băiţa-Ştei mining area, Bihor county (Romania) ”, J. Radiation Protection Dosimetry, Vol.(158), No.(4), pp. 447-452.

Mustapha, A.O., Patel, J.P. and Rathore, I.V.S. (2002). “Premiere report on radon concentration in drinking water and indoor air in Kenya”, J. Environ Geochem and Health, Vol.(24), pp. 387-396.

Nasir, T. and Shah, M. (2012). “Measurement of Annual Effective Doses of Radon from Drinking Water and Dwellings by CR-39 Track Detectors in Kulachi City of Pakistan”, J. Basic and Applied Sciences, Vol(8), pp. 528-536.

Ndontchueng, M. M., Simo, A., Nguelem, E. J. M., Beyala, J. F., Kryeziu, D. (2013). “Preliminary Study of Natural Radioactivity and Radiological Risk Assessment in Some Mineral Bottledwater Produced in Cameroon”, International J. science and Technology, Vol.(3), No.(12), pp. 372-377.

Oliveira. J, Mazzilli. B.P, Oliveira. M. H and Bambalas. E, (2001). “Natural radionuclides in drinking water supplies of Saão Paulo State, Brazil and consequent population doses”, J. Environ Radio., Vol.(53), pp. 99-109.

Oner, F, Yalim. A.H, Akkurt. A and Orbay. M, (2009). “measurements of radon concentrations in drinking water and the Yesilirmak river water in the area of Amasya in Turkey”, J. Radiat. Prot. Dosim, Vol.(133), No.(4), pp.22-32,26.

Rafat M. Amin, (2013) “Evaluation of radon gas concentration in the drinking water and dwellings of south-west Libya, using CR-39detectors”, International J. of Environmental Science Volume 4, No 4 pp.484-490.
