**Annual effective dose due to Ingestion and Inhalation of Radon in Tap-Water from some preparatory schools, Samawa City, Iraq**

**Abstract:**

Radon and itsradioactive progenies in the indoor environment have been identified as the main sources of public radiation dose. The presence of radon in drinking tap water and other household uses can increase the indoor radon level and cause radiation-related health hazards, both through inhalation and ingestion. The present research measures radon concentrations in 140 tap water samples collected from 14 preparatory schools in Samawa City (with an average of 10 samples for each school) using the active electronic radon detector RAD7. The results show that radon concentrations varied from (0.11 ± 0.6Bq/L) to (1.986 ± 1.59Bq/L) with a mean concentration of (0.605± 0.6475 Bq/L). The annual effective dose due to ingestion and inhalation was calculated. Also, the minimum and maximum mean values of the total annual effective are calculated and found to be (0.263 μSv/yr) and (2.325 μSv/yr), respectively. The measured values of radon gas activity concentrations and annual effective dose in all samples are lower than that of the safe limit prescribed by U.S. Environmental Protection Agency (11 Bq/L), 4 to 40 Bq/L suggested by United Nations Scientific Committee on the Effects of Atomic Radiation, and World health organization (100 Bq/L for radon concentration and 100 μSv/yr for annual dose), indicating no significant radiological hazards for the inhabitants in the study area.

**Keywords:** Drinking water, Radon concentration, Annual effective dose, Tap water.

1. **Introduction:**

Radon (222Rn) is a radioactive gas with a half-life of 3.824 days. It is the direct descendant of radium (226Ra) in the uranium decay chain (238U). According to estimates of the global population's total radiation dosage, natural sources account for 96% of the dose, with artificial sources accounting for 4%.[1]. Moreover, radon gas (a decay product of 226Ra) is the predominant source of natural radiation exposure to the global population. Inhalation of short-lived radon decay products (222Rn) constitutes approximately 50% of the effective equivalent dose in humans. Two progeny of 222Rn, namely 214Po and 218Po[2], are α emitters, contributing over 90% to the total radiation dose received due to radon exposure. Indoor radon exposure by inhalation has long been known to pose health risks. Indoor radon and its progenies are mostly found in construction materials, natural gas, and water from subsurface sources. Radon gas is easily emitted into the air when water is used for common household tasks like showering and cleaning. Radon gas and its decay products pose a cancer risk to the lungs if inhaled aggressively[3]. It is practically hard to prevent trace exposure in a building because construction materials are made from raw elements like concrete slabs, bricks, granite, and tiles. Radon gas concentrations may build up to potentially dangerous levels in a structure with insufficient ventilation. According to ICRP guidelines, household radon levels are typically controlled by an action level of (200–600) Bq.m-3[4]. RAD-7 solid state radon detector is an efficient short-term monitor used in this study because of the possibility of in-situ measurements, which ensures accuracy, in addition to high sensitivity and efficiency. Several works have been carried out to assess radon concentration levels in water samples collected from different locations in Iraq. Still, there is an observable lack of such studies within Samawa City. In contrast, similar works, especially regarding radioactive contamination in schools and the accompanying health risks that threaten the lives of students. From this standpoint, this study aims to investigate radon concentration levels in the drinking water of some preparatory schools and hence compare these levels with the permissible limits reported by international agencies to establish a clear understanding of the hazards that could threaten students' health. Furthermore, based on the results conducted, the annual effective dose due to ingestion and inhalation will be carried out for the same purpose.

**2. Materials and Methods:**

 **2.1 Study Area:**

The present study was conducted in preparatory schools in Samawa City, the main city in Al-Muthanna province, Iraq, which occupies 680 km² and has a population of about 316.426. It is situated in geographic coordinates 31° 19′ 0″ N and 45° 17′ 0″ E, with an elevation of 9 m (29 ft) above sea level. The city is 280 kilometers southwest of Baghdad, the capital of the Republic of Iraq, in a region characterized by high summer and relatively low temperatures in winter. Samawa City may experience strong southerly winds during late winter and spring, which can lead to dust storms. Conversely, a mild northwesterly breeze is exceedingly hot and arid throughout the extended summer months, potentially leading to fast dehydration. Only the surface water (the Euphrates River), which is pumped out during the purification process, was available to this metropolis due to its high water demand. Significant temperature fluctuations, high aridity, and minimal precipitation characterize the city's climate. Samawa areas have calcareous clay to silty clay and yellowish-brown soil, with features that change over long distances. In numerous locations, they are combined with sandy substances[5].

2.2 **Sampling and Sample Analysis:**

 In this study, tab water samples were collected in 250 mL vials and analyzed promptly at the sampling site. The interval between sample collection and analysis was a few minutes; hence, no radon decay transpired in the water. The RAD-7 detector immediately converts alpha radiation into an electrical signal. RAD-7 can differentiate between aged and recent radon[6]. RAD H2O provides data following a 30-minute examination, exhibiting sensitivity that equals or surpasses that of liquid scintillation techniques. The RAD H2O method utilizes a closed-loop aeration system in which the air and water volumes remain constant and unaffected by the flow rate. The air passes through the water, persistently removing radon until equilibrium. One hundred forty tap water samples were obtained from 14 preparatory schools, with an average of 10 samples each. A calibrated portable continuous radon monitor, RAD7, is employed for measurements. Figure (1) illustrates the schematic diagram of the RAD7 configuration for measuring radon in water.[7]. In the RAD-H2O system, a 250 mL sample bottle was linked to the RAD7 detector via a bubbling kit and desiccant tube to produce a closed-air loop. The external architecture of RAD7 comprises a plastic casing including an upper control interface that includes a keypad, an infrared LED, an LCD, an air outlet, inlet ports, and a computer serial port, as illustrated in Figure (2). To guarantee the accuracy of the sample measurements, each sample underwent four cycles of five minutes each[8], with an initial aeration time of 5 min. This means that RAD7 is capable of accurately measuring radon concentration in a water sample within 20 min, which is a very short time compared with 3.825 days half-life of radon, thereby making RAD7 a very good detector for evaluation of radon in water[9]. At the end of the run, the RAD7 automatically prints out the mean radon concentration from the four cycles counted, or it can be saved the results on the computer memory using RAD7 capture software presided by the manufacturer, which allows displaying Rn222 concentration for each cycle[10].



 **Figure (1):** Schematic diagram of RAD-H2O assembly. **Figure (2):** RAD7, An electronic radon detector.

**2.3** **Annual effective dose calculation:**

The annual effective dose due to the ingestion of radon from drinking water **(Hing)** was calculated according[11]**:**

$H\_{ing} (^{mSv}/\_{yr}) = C\_{Rn} x D\_{ing} x L$ ***………………*(1)**

Where: ***CRn*:** mean radon concentration in drinking water **(Bq/L)**

**Ding:** The conversion factor for ingestion **( 1x10-8 *Sv/Bq* or 1x10-5 *mSv/Bq)*for an adult and 2x10-8 *Sv/Bq* or 2x10-5 *nmSv/Bq* for a child)**[12].

***L:*** annual drinking water consumption in liters.

 There have been controversies over annual water intake in a year. The value of (60 L/y) for the weighted direct annual consumption of tap water has been proposed by UNSCEAR[13]. The total annual water intake for the so-called ‘‘ICRP Standard Man’’ equals (2L/d ) or (730 L/y ) for adults and children, and the average water consumption rate (ACR) was (1.5L/d) or (547.5 L/y) [14]The southwestern area of Iraq has a desert climate and is the driest area of the country. In addition, Samawa has a high temperature most days of the year, which means it consumes a large quantity of water. For consistency with most international drinking water guidelines, the ICRP amount was applied to calculate the ingestion dose in this study[15]. The annual effective dose due to the inhalation of radon (Hinh), resulting from the radon concentration in drinking water, was calculated using the following relation[16]:

$H\_{inh} (nSv/yr) = C\_{Rn} x R x F x T x D$ **…………….(2)**

Where:

***CRn***$:$Meanradon concentration in drinking water **(Bq/m3).**

***R*:** air to water concentration **(10-4).**

***F*:** Equilibrium factor between indoor radon and its progeny **(0.4).**

***T*:** Exposure time in hours **(7000 hr/yr)** for adults and children.

***D*:** Dose conversion factor **(9 *nSv/(Bq hr/m*3)) or (9**$×$**10--3 *μSv/(Bq hr/m*3))**[17].

1. **Results and Discussion:**

 The radon activity concentration in the residential drinking tap water was analyzed for 14 preparatory schools in Samawa city-Iraq, with 10 samples for each. In the study area, residential tap water is obtained from the surface water of the Euphrates River. The result for 14 schools is reported in table (1). As shown from the table, the radon activity concentrations from each preparatory school of the study area were found to range from (**0.11 ± 0.6** Bq/L) to (**1.986 ± 1.59** Bq/L) with a mean concentration of (**0.605± 0.6475** Bq/L). However, these recorded values of radon concentration in the drinking tap water were below the permissible value of 11 Bq/L recommended by the USEPA and 100 Bq/L recommended by the EU and WHO[18], or the UNSCEAR value of 4 to 40 Bq/L [19], and or within or lower than ICRP suggested maximum contamination level of radon concentration in water samples as 0.6 Bq/L [20]. As seen in Figure (3) and Table (1), the measured radon concentration in the (AL-Rayaan) school is higher than that of measured activity in other schools. Perhaps this is because of the rock and soil structure through which the water pipes run or because this school is supplied with water by the oldest water network in the city. Furthermore, the network pipes are constructed from concrete; it is established that the radon concentration in concrete pipes exceeds that of PVC or iron pipes. Conversely, these pipelines have numerous fractures and fissures, facilitating the mingling of groundwater with conveyed water and elevating the pipes' radon concentration. Consequently, the pipes' composition and the soil's characteristics will influence the concentration of radon gas in drinking water. The lowest radon activity concentration value was measured in the samples from the (AL-Suwdid) school. This low value could be due to the school being close to the processing stations or the newly created water network. Hence, its transportation lines lack cracks or fissures, which helps avoid additional contamination. In the scope of our results, the measured radon activity concentration values in the water sample are marginally lower than or within the limit value of 0.6 Bq/L given by the International Commission on Radiological Protection (ICRP)[21].

The radon activity concentration observed in the drinking water of this study region has been compared with the outcomes of similar studies carried out in Iraq and different parts of the world, as shown in Table (2). The average radon concentration reported in this study was in the range of those reported in other parts of Iraq. On the other hand, the annual effective dose due to ingestion and inhalation from exposure to Rn222 in water for adults has been calculated using equations (1) and (2). The calculated total annual effective dose ranged from (0.263 μSv/yr) at AL-Suwdid school to (2.325 μSv/yr) at AL-Rayaan school, with an average value of (1.294 μSv/yr).

The World Health Organization (WHO)[22] and the European Council[23]. The recommended action level for the yearly ingestion dosage from water drinking is 100 μSv/year. The WHO states that if the total annual effective dose is below 100 μSv/yr, the water is suitable for drinking, and no additional corrective measures are required. The overall annual effective dosage from all locations in the analyzed area was far below the WHO standard limit of 100 μSv/yr, indicating no health risks associated with the Radon-222 dose from water in the region that a discrepancy exists in measuring.

 **Conclusion:**

 The current study shows that the Radon concentrations in the schools' water are much below the safe limit value advised. The geological physiographic region, nature, and sample sites all contributed to the variances in the radon concentrations in the water. Most of these schools possess a water source that is not piped but consists of tanks (tankers) in the study areas, which students use for drinking and washing. This study aimed to assess the impact of this gas; also, natural water contamination is a worldwide issue that warrants significant attention due to its environmental dangers and threats to human health and economic repercussions. The presence of these ions is of special concern among the many different types of contaminants that impact water resources because of their high toxicity, even at low concentrations.

**Table (1):** Radon activity concentrations in drinking water

|  |  |  |  |
| --- | --- | --- | --- |
|  **Mean** | **Rn Concentration (Bq/L)** | **Schools name** | **No.** |
| **Max** | **Min** |
| **0.6255 ± 0.93** | **0.901 ± 1.26** | **0.35 ± 0.6** | **AL-Mutafawiqat** | **1** |
| **0.6075 ± 0.47** | **0.895 ± 0.34** | **0.32 ± 0.6** | **AL-Mutamayizat** | **2** |
| **0.306 ± 1.15** | **0.432 ± 1.71** | **0.18 ± 0.6** | **AL-Kanadiu** | **3** |
| **0.575 ± 0.65** | **0.849 ± 1** | **0.31 ± 0.3** | **AL-Aiqmar** | **4** |
| **0.429 ± 0.45** | **0.599 ± 0.3** | **0.26 ± 0.6** | **Am AL-Banin** | **5** |
| **1.303 ± 1.045** | **1.986 ± 1.59** | **0.62 ± 0.5** | **AL-Rayaan** | **6** |
| **0.591 ± 1.15** | **0.873 ± 1.9** | **0.31 ± 0.4** | **Eishtar** | **7** |
| **0.512 ± 0.63** | **0.694 ± 0.65** | **0.33 ± 0.6** | **Zuha Hadid** | **8** |
| **1.221 ± 1.1** | **1.852 ± 1.61** | **0.59 ± 0.5** | **AL-Zuhur** | **9** |
| **0.536 ± 0.605** | **0.732 ± 0.61** | **0.34 ± 0.6** | **AL-Tamayuz** | **10** |
| **0.281 ± 0.45** | **0.393 ± 0.49** | **0.17 ± 0.4** | **AL-Qalea** | **11** |
| **0.4895 ± 0.96** | **0.749 ± 1.32** | **0.23 ± 0.6** | **AL-Mawahib** | **12** |
| **0.352 ± 0.74** | **0.594 ± 0.88** | **0.11 ± 0.6** | **AL-Suwdid** | **13** |
| **0.6355 ± 0.77** | **0.811 ± 0.94** | **0.46 ± 0.6** | **AL-Um Alfadila** | **14** |
| **0.605± 0.6475** | **0.883 ± 0.895** | **0.327 ± 0.4**  | **Mean Value** |

**Table (2):** Comparison between the present results and the data published by other investigators in neighboring countries.

|  |  |  |
| --- | --- | --- |
| **Country** | **Rn222 (Bq /L)** | **Reference** |
| Turkey, Adıyaman (drinking water) | 0.39 – 0.51 | [24] |
| Turkey, Kastamonu (drinking water) | 0.50 – 5.78 | [25] |
| Saudi Arabia, Qassim (Groundwater) | 1.20 – 15.43 | [26] |
| Saudi Arabia, Jazan (drinking water) | 1.65 – 3.82 | [27] |
| Iran, Kerman (drinking water) | 1.2 – 9.88 | [28] |
| Iran, Taft Township (drinking water) | 0.881 – 20.36 | [29] |
| Iran, Mashhad City (drinking water) | 0.064 - 46.088 | [30] |
| Jordan (drinking water) | 3.9 -117 | [31] |
| Lebanon (well and spring water) | 0.91 – 49.6 | [23] |
| Kuwait (drinking water) | 1.02 – 6.05 | [32] |
| Palestine (residential tap water) | 1.0 | [33] |
| Iraq, Baghdad Government (Tap Water) | 0.012 – 0.283 | [6] |
| Iraq, Erbil Governorate (Drinking Water) | 0.069 – 13.062 | [34] |
| Iraq, Baghdad, Al-Mustansiriyah(Tap Water) | 0.073 – 0.190 | [35] |
| Iraq, Hilla City (drinking water) | 0.0361 – 0.193 | [36] |
| USEPA | 11.1 | [37] |
| UNSCEAR | 10 | [17] |
| WHO | 100 | [20] |
| Iraq, Samawa city | 0.067 – 0.615 | Present Study |

Figure (3): Bar diagram showing variation in radon concentration of the water samples

**Disclaimer (Artificial intelligence)**

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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