Measurement of Annual Effective Doses of Radon from Drinking Water and Dwellings by CR-39 Track Detectors in Kulachi City of Pakistan

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Abstract: Radon concentration and annual effective doses were measured in drinking water and dwellings of Kulachi city of Pakistan. Twenty samples of drinking water were collected from various sources i.e. tap water, pond water, hand pump and tube well water. CR-39 (Columbia Resin-39) based NRPB (National Radiological Protection Board) radon dosimeters were used to measure the radon concentration. Among the various types of samples, the maximum average value of radon concentration was detected (1.218±0.005 Bq/L) in tube well water while the minimum average value was (0.602±0.003 Bq/L) in tap water. The annual effective dose was calculated from the measured radon concentration which varied from 4.39×10^{-3} to 8.89×10^{-3} mSv/y. The measured values of radon concentration as well as the annual effective dose were found within the United States Environmental Protection Agency (US-EPA) and World Health Organization (WHO) recommended limits.

In order to carry out radon survey in dwelling, thirty CR-39 based NRPB dosimeters were installed in various buildings in the area under study. The maximum measured indoor radon concentration was found to be 270±22 Bq/m^3 while the minimum was 21±2 Bq/ m^3. The mean value of indoor radon concentration in bed rooms was 98 Bq/m^3 which was within the International Commission on Radiological Protection (ICRP) recommended limits however, maximum concentration of 240 Bq/m^3 was observed in a mud made room which was above the US-EPA and WHO new recommended limits. The mean annual effective dose from indoor radon was found to be 1.546 mSv/y which was within the ICRP recommended limits.

Keywords: Drinking water, Dwellings, CR-39, NRPB dosimeters, Radon concentration, Annual effective dose.

1. INTRODUCTION

Environmental pollution has been a great threat to humanity since the beginning of life on earth. So it is natural for us to be sensitive and active against all the pollutants causing threats to our lives. As we know that radon is a radioactive gas present in our drinking water and the air we breathe and a major cause of lungs cancer in many countries, so it is a matter of great interest for us to inform our people about this hidden foe. The International Commission on Radiological Protection (ICRP) suggests that radio nuclides in water are absorbed more easily than radio nuclides incorporated in food [1]. In groundwater, ^{222}Rn occurs in a dissolved form and its activity concentration may vary from a few Bq/L to thousands of Bq/L. The highest activity concentrations are found from bedrock water. In surface water ^{222}Rn is generally found at very low levels [2, 3].

Radon in domestic water supplies can cause human exposure to a radiation dose both through inhalation and ingestion. Radon is soluble in water, its solubility decreases rapidly with an increase in temperature. When a tap or shower is turned on, some of the dissolved radon is released into indoor air. This adds to the radon present from other sources and will give rise to a radiation dose when inhaled [4]. It has been estimated that 1000 Bq/L of radon in water will, on average, increase the radon concentration in indoor air by 100 Bq/m^3 [5].

High concentration of radon in drinking water causes stomach cancer [6- 8]. The cancer risk arising from ingested ^{222}Rn is derived from calculations of the dose absorbed by the tissues [9]. The National Research Council (1999) has estimated that about 30% of the activity concentration of ^{222}Rn in the stomach was integrated in the walls of the stomach.

The problem of health risks from radon in dwellings has been of serious concern to international organizations and commissions such as International Commission on Radiological Protection (ICRP), World Health Organization (WHO), United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) etc [10]. The International Commission on Radiation Protection (1993) recommends that all the countries of the world should carryout radon survey to find radon prone areas. According to UNSCEAR the population weighted global average radon concentration is 40 Bq/m^3 indoor and 10% Bq/m^3 outdoor [11]. According to WHO a national reference level of 100 Bq/m^3 is recommended.

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Considerable data is available on measurement of radon concentration in drinking water and dwellings [12- 20]. However the present study is first ever survey of radon measurement in drinking water and dwellings of Kulachi, Pakistan.

2. AREA OF STUDY

Kulachi is situated immediately below the Sulaiman mountains, between 30° 15" and 32'° 17" N and 70° 11" and 70° 42" E at an altitude of 209 metres, with an area of 1,509 square miles. It is situated 45; km from Dera Ismail Khan in the Daman valley of the Sulaiman Range, and lies on the Banks of the Gomal River, a tributary of the Indus. The city's population is about 35,000. It has stony plain and the line of barren and unsightly hills which form its western border. The plain is much cleft by deep channels which carry off the rain-water from the hills, and these are utilized for irrigation with great skill [21]. Its climate is mostly dry and hot. The location of Kulachi is indicated in the Map of Pakistan (Figure **1**).

3. EXPERIMENTAL METHOD

3.1. Experimental Method for Water

The main drinking water sources in the area under study are tap water, hand pump, tube well and pond. A total number of 20 samples of different sources of drinking water were collected from different locations (city and surroundings) of Kulachi.

The locations of the sampling points are indicated in the map (Figure **2**).

The samples were collected in well washed bottles which were sealed immediately so that radon may not get out of it. The bottles were marked and date and time of sample collection were written upon them. The samples were brought to Applied Radiation laboratory of the Physics Department, Gomal University Dera Ismail Khan. Sheet of CR-39 track detector of 500 µm thickness was cut into square pieces of 2×2 cm^2 and these were fixed in National Radiological Protection Board (NRPB) dosimeters with adhesive tape. The 500 ml of each sample was put in a plastic container of height 27.5 cm (volume 10.2×10^3 cm^3) with sample surface area 369.6 cm^2. CR-39 based NRPB (National Radiological Protection Board) radon dosimeters were installed in these containers at a height greater than 25 cm from the water level to avoided Thoron contribution [10, 22, 23]. The containers were sealed and the detectors in the container were exposed for three months. In the beginning the radon level is zero in the chamber of the dosimeter. The radon activity level slowly rises from zero to equilibrium value (when the

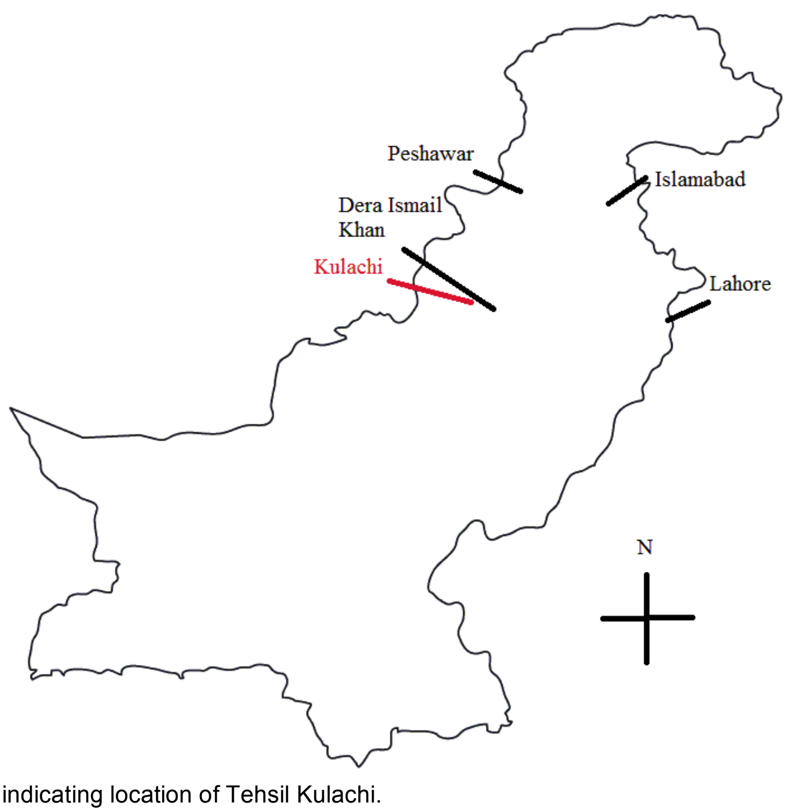


Figure 1: Map of Pakistan indicating location of Tehsil Kulachi.

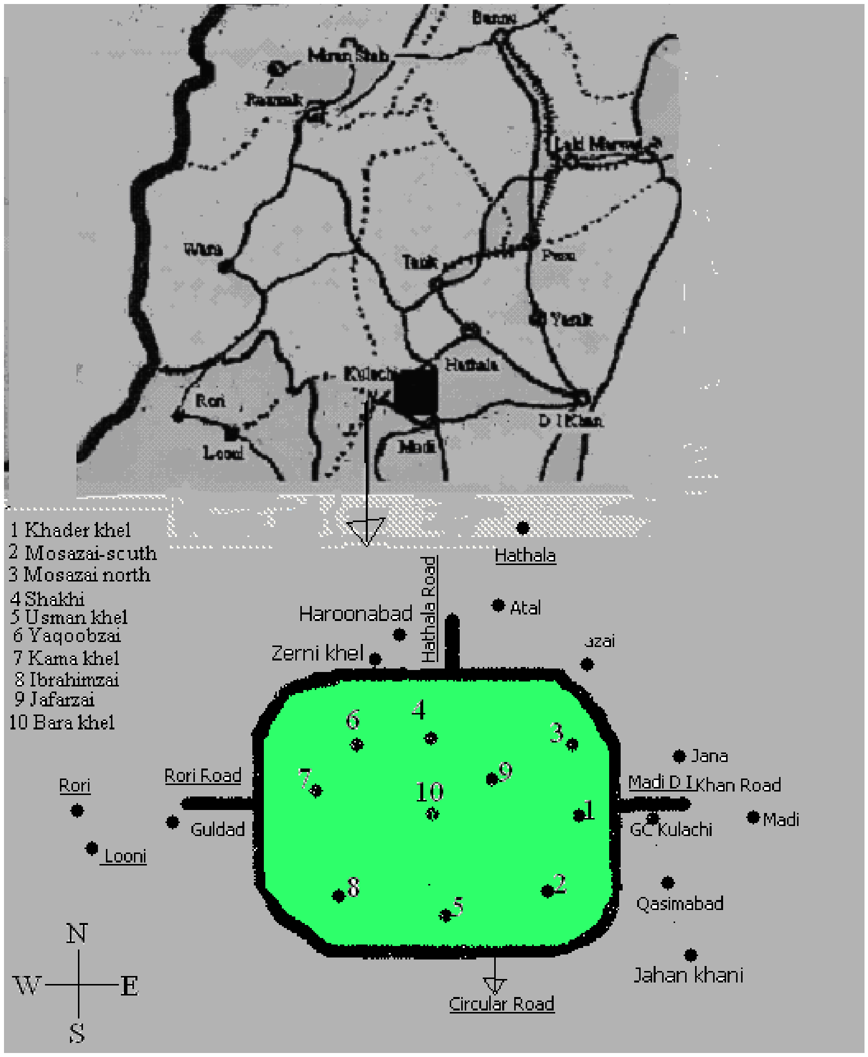


Figure 2: Map of Kulachi indicating sampling points.

decay and build up rates of radon balance each other). The effective exposure time of the detectors was calculated by the following relation [10].

$$T_{effective} = t - \tau\left(1 - e^{-\lambda t}\right) \quad (1)$$

where t = total exposure length (days)

λ = radon decay constant (7.55×10^{-3} h^{-1})

and τ = Mean life of radon (5.5 days)

This correction is made in all finite exposures only in closed systems [10]. The effective time calculated for three months exposure is 2028 hrs.

3.2. Experimental Method for Dwellings

In case of dwelling different buildings were selected in different areas of the Kulachi city (Figure **2**). The most of the houses selected for the study were made of backed bricks, sand and cement, and few were mud made. Majority of the houses were single storey. The size of the rooms was approximately 14×16×11 ft^3 with single window. The class rooms and laboratories of the Government College were well ventilated but the stores were almost closed.

Thirty CR-39 based NRPB dosimeters were installed at a height of 6ft from the ground level in bedrooms, stores, drawing rooms, verandas, kitchens, offices, laboratories and class rooms. The dosimeters were installed at a height of 6ft in order to keep them in breathing zone. The dosimeters were exposed to the indoor environment for a period of three months from 2nd February, 2010 to 1st May, 2010.

After three months the detectors were chemically etched in 6M NaOH solution at 70ºC for 16 hours. The etched detectors were cleaned in running water and washed with alcohol and dried. After etching the

Table 1: Radon Concentration in Drinking Water Samples

Sample No.	Location	Source	Radon Concentration (Bq/L)
M-1	Mohallah Khader Khel	Tap water	0.453±0.003
M-2	Mohallah Bara Khel	Tap water	0.903±0.004
M-3	Mohallah Moosa Zai north	Tap water	0.848±0.003
M-4	Mohallah Moosa Zai south	Hand pump	0.748±0.003
M-5	Mohallah Kamal Khel	Tap water	0.788±0.003
M-6	Rana-zai	Pond	1.311±0.005
M-7	Mohallah Qasim Abad	Tube well	1.455±0.006
M-8	Gara Jahan Khani	Tube well	1.315±0.004
M-9	Madi	Pond	1.262±0.005
M-10	Rori	Tape water	0.333±0.002
M-11	Looni	Pond	1.003±0.004
M-12	Hathala	Tube well	0.670±0.003
M-13	Atal Shreef	Pond	1.123±0.004
M-14	Govt. College, Kulachi	Tube well	1.433±0.005
M-15	Gara Guldad	Pond	0.503±0.003
M-16	Zarni Khel	Hand pump	0.977±0.004
M-17	Rori	Pond	1.055±0.004
M-18	Yaqoob Zai	Tap water	0.429±0.003
M-19	Gara Jana	Pond	1.307±0.005
M-20	Haroon Abad	Tap water	0.466±0.003

detectors were studied under optical microscope and track densities were measured.

4. RESULTS AND DISCUSSION

4.1. Measurement of Radon Concentration

i. Radon Concentration in Drinking Water

The measured track densities were converted into radon concentration by using the following conversion factor [22].

2.7 tracks/cm^2/hr = 1 KBq/m^3 = 1 Bq/L

Radon concentration calculated for each water sample by using above conversion factor is given in Table **1**.

The minimum, maximum and the average values of radon concentration in different type of water sources are given in Table **2**.

The average value of radon concentration in four types of drinking water samples varied from (0.602±0.003) to (1.218±0.005) Bq/L. Minimum average value was found in tap water while the maximum average value was found in tube well water. Tube well water was taken directly from tube well which comes from a depth of more than 150 feet and radon

Table 2: Minimum, Maximum and Average Radon Concentration in Various Sources of Drinking Water of Kulachi City

Source of water	No. of samples	Rn^{222} concentration (Bq/L)		Arithmetic Mean (Bq/L)
		Minimum	Maximum	
Tap water	7	0.333±0.002	0.903±0.004	0.602±0.003
Pond water	7	0.503±0.003	1.311±0.005	1.081±0.004
Hand pump water	2	0.748±0.003	0.977±0.004	0.863±0.004
Tube well water	4	0.670±0.053	1.455±0.005	1.218±0.005

concentration is usually high in ground water as compared to surface water [24]. ^{222}Rn the decay product of ^{226}Ra is the part of ^{238}U series. Trace amounts of uranium and radium are present in rocks and soil. Being a gas radon can move freely through the pores of soil and rocks. Under the water table, when these pores are filled with water, radon is dissolved into the water and is transported with it. Therefore, radon concentration is usually high in ground water as compared to surface water.

Tap water which is supplied to the public is also obtained from tube well. People store this water in small tanks for daily use and after passing through pipes it is used in kitchens and bathrooms. Low level of radon in piped treated water is due to the fact that most of the dissolved ^{222}Rn in water is desorbed during treatment [24].

The average value of radon concentration in pond water and hand pump water was found to be (1.081±0.004) and (0.863±0.004) Bq/L respectively. The samples of pond water were collected from the villages around Kulachi city. People in these villages have no proper source of drinking water. Rain water flowing from the surrounding areas is stored in these ponds which contains lot of mud. Higher value of radon concentration in pond water may be attributed to enhanced radium contents in mud [25].

According to United States Environmental Protection Agency (US-EPA) the safe level of radon in drinking water is11 KBq/m^3 or 11 Bq/L (300 pC/L) [26]. The results obtained of the studied area are much below this level.

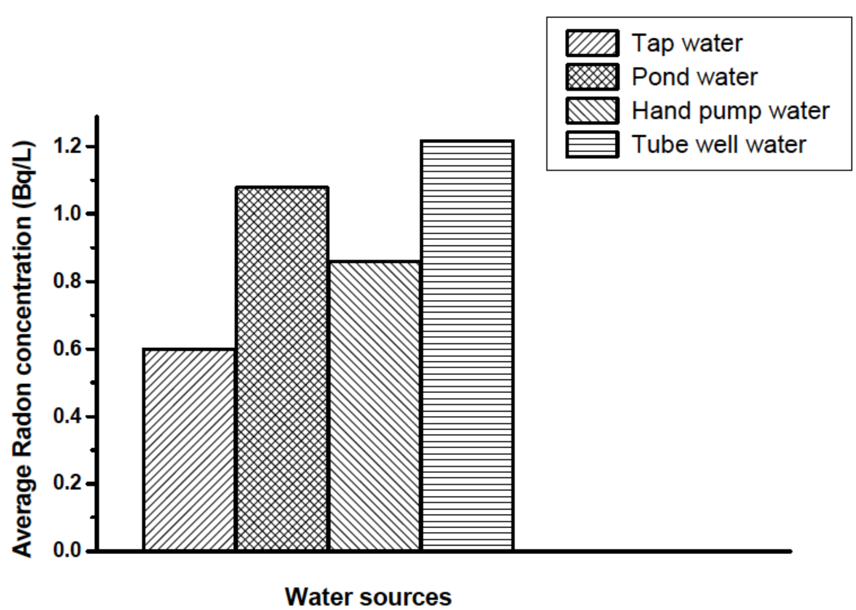
The average radon concentration in various sources of water is shown in Graph **1**.

ii. Radon Concentration in Dwellings

In order to measure radon concentration in dwellings thirty dosimeters were installed in various buildings at different locations of Kulachi city. The main focus was bedrooms, stores, kitchens and college class rooms. The value of radon concentration in each room is given in the Table **3**.

The minimum, maximum and the average values of radon concentration in different type of rooms are given in Table **4**.

The radon reference level i.e. the level above which action should be taken is different in different countries. ICRP recommends a maximum limit of 600 Bq/m^3 [27]. The US-EPA recommended level is 150 Bq/m^3 [28]. The WHO new recommended maximum indoor radon level is 100 Bq/m^3 [29]. In the present study, the indoor radon levels are within the ICRP limits. However, levels of few houses are above the US-EPA and WHO new recommended limits. The average radon concentration in each type of room is shown in Graph **2**. The highest average radon level of 133±11 Bq/m^3 is observed in stores. This may be due to the fact that most of the time stores are closed and hence due to poor ventilations radon concentrations are higher. The mean value of indoor radon concentration in bed rooms was



Graph 1: Average Radon concentrations in various sources of water in Kulachi.

Table 3: Radon Concentration in Dwellings of Kulachi

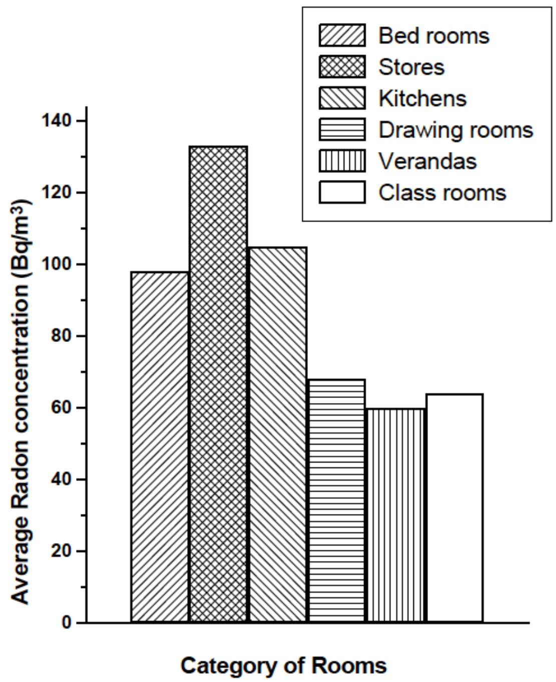
Sample No.	Location	Types of rooms	Radon Concentration (Bq/m^3)
M-21	Mohallah khader khel	Bed room	43±4
M-22	do	Kitchen	199±16
M-23	do	Store	40±4
M-24	do	Veranda	64±6
M-25	do	Drawing room	48±5
M-26	Mohallah Bara khel	Bed room	29±3
M-27	do	Store	270±22
M-28	do	Drawing room	35±3
M-29	Moosazai south	Bed room	117±9
M-30	do	Store	150±11
M-31	Moosazai north	Drawing room	129±10
M-32	do	Kitchen	109±9
M-33	Mohallah Usman khel	Bed room	162±13
M-34	do	Veranda	35±3
M-35	do	Kitchen	32±3
M-36	Mohallah Jafer zai	Bedroom(mud)	240±20
M-37	do	Veranda	81±8
M-38	do	Drawing room	58±5
M-39	Mohallah Qasim Abad	Bed room	48±4
M-40	do	Store	133±10
M-41	Govt College	Class room	87±8
M-42	do	Lab	112±9
M-43	do	Bed room	53±5
M-44	do	Office	34±3
M-45	do	Hall	21±2
M-46	Collge Hostel	Bed room	44±4
M-47	do	Kitchen	79±8
M-48	do	Bed room	87±8
M-49	Panwar street	Bedroom (mud)	156±13
M-50	do	Store	70±7

Table 4: Minimum, Maximum and Average Radon Concentration in Various Types of Rooms of Kulachi

Types of rooms	No. of samples	^{222}Rn concentration (Bq/m^3)		Arithmetic Mean (Bq/m^3)
		Minimum	Maximum	
Bed rooms	10	29±3	240±20	98±8
Stores	5	40±4	270±22	133±11
Kitchens	4	32±3	199±16	105±9
Drawing rooms	4	35±3	129±10	68±6
Verandas	3	35±3	81±8	60±5
Class rooms	4	21±2	112±9	64±6

98 Bq/m^3 but a maximum value of 240 Bq/m^3 was observed in a mud made room. This is because mud or unbaked bricks have higher radon emanation rate. Paints and distemper minimize leakage of radon

through pores of walls [30]. Also activity concentration of ^{226}Ra is higher in clay bricks then cemented bricks [31]. The other reason of higher value of radon concentration was bad ventilation. In these mud made rooms there was no window for cross ventilation [18].



Graph 2: Average radon concentrations in various types of rooms.

In Graph **3** the number of rooms surveyed is plotted against the indoor radon concentration. The number of rooms falling in the range from 0-50, 51-100, 101-150, 151-200 , 201-250 and from 251-300 are 37%, 27%, 17%, 13%, 3% and 3% respectively. Around 81% of the surveyed rooms are within the US-EPA limit and 64 % are in the WHO new acceptable limit.

4.2. Measurement of Annual Effective Dose

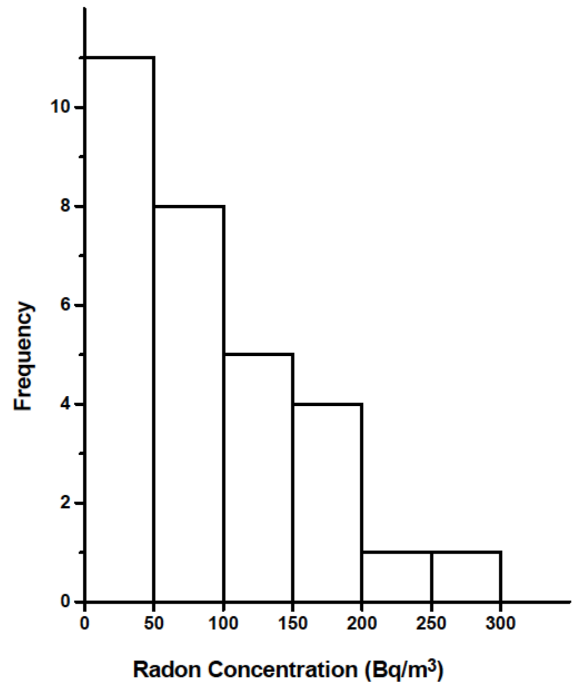
i. Annual Effective Dose from Drinking Water

The annual effective dose (mSv/y) was calculated by taking in account the activity concentration of Radon (Bq/L), the dose coefficient (Sv/Bq) and the annual water consumption (L/y) according to equation 2 [32].

$$E = C \times D \times L \qquad (2)$$

Where C is the concentration of radon (Rn^{222}), D is the dose coefficient (10^{-8} Sv/ Bq) and L is annual water consumption by an adult in litres. We have used daily water consumption by an adult as 2 litres [11].

For a given radon concentration, the estimated dose varies significantly with the water consumption rate and



Graph 3: Indoor radon concentrations in dwellings.

the dose conversion factor used [32]. The estimated dose coefficient by the United Nations Scientific Committee on the Effects of Atomic Radiation due to ingestion of radon from water is 10^{-8} Sv/Bq for an adult, 2×10^{-8} Sv/Bq for a child and 7×10^{-8} Sv/Bq for an infant [32]. The annual effective dose received by an adult from different type of water sources is given in Table **5**. According to UNSCEAR (2000), doses to children and infants for similar consumption rates could be a factor of 2 and 7 higher, respectively [32].

Table 5: Annual Effective Dose Received by an Adult from Various Sources of Drinking Water in Kulachi City

No.	Source of water	Annual Effective Dose (mSv/ y)
1	Tap water	4.39×10^{-3}
2	Pond water	7.89×10^{-3}
3	Hand pump water	6.29×10^{-3}
4	Tube well water	8.89×10^{-3}

The annual effective dose varied from 4.39×10^{-3} to 8.89×10^{-3} mSv/y for tap water to tube well water respectively. The calculated maximum value of annual effective dose from ^{222}Rn ingested with water is much below the recommended value of 0.1 mSv for public [33, 34].

ii. Annual Effective Dose from Indoor Radon

From the measured indoor radon concentration for bedrooms, expected annual effective doses received

Table 6: Annual Effective Doses of Radon Received from Bedrooms

Sample No.	Location	Types of room	Annual Effectiv Dose (mSv /y)
M-21	Mohallah khader khel	Bed room (cemented)	0.678
M-26	Bara khel	Bed room (cemented)	0.457
M-29	Moosa zai south	Bed room (cemented)	1.844
M-33	Mohallah Usman khel	Bed room (cemented)	2.554
M-36	Mohallah Jafer zai	Bed room(mud made)	3.815
M-39	Mohallah Qasim Abad	Bed room (cemented)	0.756
M-43	Collge Hostel	Bed room (cemented)	0.835
M-46	Collge Hostel	Bed room (cemented)	0.693
M-48	Collge Hostel	Bed room (cemented)	1.371
M-49	Panwar street	Bed room (mud made)	2.459
Arithmetic Mean			1.546

by the residents of the surveyed area were calculated using equation 3, the UNSCEAR model (2000) [35]

$$E = C \times H \times F \times D \times T \quad (3)$$

Here C is the radon (Rn^{222}) concentration (Bq/m^3), F is equilibrium factor (0.4), H is the occupancy factor (estimated 0.5 for the dwellers i.e 12 hours out of 24),T is hours in a year (8760) and D is the dose conversion factor (9×10^{-6} m Sv/h per Bq/ m^3).

The annual effective doses from indoor radon received by the dwellers of Kulachi city are given in the Table **6**. The annual effective dose varied from 0.457 to 3.815 mSv/y with an average of 1.546 mSv/y. The average value of annual effective dose from inhaled radon is less than the ICRP recommended limits of 3-10 mSv/y [27].

5. CONCLUSIONS

Radon concentration in drinking water and dwellings of Kulachi city of Pakistan has been measured. From the measured radon concentration annual effective doses received by the inhabitants of the surveyed area have been estimated. The minimum average value of radon concentration is found in tap water which is used by maximum population of the surveyed area while the maximum average value is in tube well water. Low level of radon in piped treated water is due to desorption of the dissolved ^{222}Rn during treatment and high level of radon in tube well water is due to high radon concentration in ground water as compared to surface water. Our results of the studied area are much below US-EPA safe level of radon in drinking water i.e. 11 KBq/m^3 or 11 Bq/L (300 pC/L). However it is suggested that tube well water should be boiled in a well-ventilated area before use because radon concentration is reduced by boiling.

The highest average radon concentration in dwellings has been observed in mud made rooms followed by store rooms while minimum average concentration was noticed in bed rooms. Maximum value of radon concentration in stores and minimum in bed rooms may be attributed to poor and well ventilation conditions, respectively. The high radon level in mud made rooms suggests that the building materials and structure of rooms influence the indoor radon levels. The improvement of ventilation in stores and coating of mud walls with plaster can reduce radon concentration.

The annual effective doses from radon ingested with drinking water and inhaled from indoor air are less than the ICRP recommended limits.

So it is concluded that radon level in most of the dwellings as well as in water sources of the Kulachi are within the limits as proposed by ICRP, US-EPA and WHO etc. However, people living in mud made and poor ventilated houses and using drinking water directly from tube well or ponds are at higher risk.

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