# MEASUREMENT OF WATERBORNE RADON IN THE DRINKING WATER OF THE DERA ISMAIL KHAN CITY USING ACTIVE AND PASSIVE TECHNIQUES

by

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Scientific paper
DOI: 10.2298/NTRP1502139N

**Groundwater is considered to be the second largest contributor to the indoor radon concentration after soil. Therefore, measurement of waterborne radon has remained a point of interest for many researchers. The main objective of this study is to study waterborne radon activity in the city of Dera Ismail Khan. In this context, water samples were collected from different locations of the city and waterborne radon was measured using a pylon vacuum water degassing system and CR-39 based radon detectors. The pylon system measured waterborne radon activities in samples of hand pumps and motor driven pumps varying from 0.015 to 0.066 Bq/L and 0.021 to 0.145 Bq/L with average values of 0.041 0.015 Bq/L and 0.076 0.024 Bq/L, respectively. Whereas CR-39 based measured values ranged from 0.042 to 0.125 Bq/L and 0.075 to 0.158 Bq/L with average values of 0.081 0.021 Bq/L and 0.120 0.020 Bq/L, respectively. The estimated average annual effective dose due to ingestion of radon from drinking water using pylon and CR-39 based radon detectors for hand and motor pump samples was found to be 1.055 $10^{-4}$ mSv and 1.947 $10^{-4}$ mSv, and 2.067 $10^{-4}$ mSv and 3.058 $10^{-4}$ mSv, respectively. The waterborne radon concentrations and as a result the annual effective dose expected to be received from it are within the recommended safe limits.**

*Key words: drinking water, pylon system, CR-39, radon concentration, annual effective dose*

## INTRODUCTION

Water is an essential requirement for all usual domestic purposes, including drinking, food preparation, personal hygiene, *etc*. Groundwater contains dissolved radon due to its contact with rocks containing natural uranium and radium [1]. The mole fraction solubility of the gas in water is 2.3 $10^{-4}$ at a temperature of 15 °C, which is about ten times more than that for oxygen gas [2]. Water-saturated soil with a porosity of 20 % and a radium concentration of 40 Bq/kg, which is the world-wide average in the earth's crust, causes at equilibrium a radon concentration in ground water of the order of 50 Bq/L [1].

Groundwater from wells and boreholes usually contains higher radon concentrations than that of surface waters. Radon present in surface waters, such as lakes and rivers, is readily released into the outdoor air by agitation as it passes over rocks and soils. Water from drilled wells is expected to contain a higher concentration of radon due to its contact with U-rich rocks for a much longer time period [3, 4]. A dug well contains mainly surface water and is not so deep. Water from public water supplies has normally also very small radon levels because water is treated in open air and radon gas is released from the water. However, a private household water supply is more or less a closed system which is extracted from the drilled borehole to the tap point indoors [3]. In some extreme circumstances, very high radon concentrations may be found in drinking-water supplies from these sources [5].

Radon in domestic water may cause health hazards in two ways. The radon may be emitted from the water thereby giving rise to exposure by inhalation. Alternatively, if the water is drunk before the radon emission, it may irradiate the gastrointestinal tract thereby giving an internal dose to the lining of the stomach [5, 6]. It has been estimated that a radon concentration of 1000 Bq/L in drinking-water discharged from a tap or shower will, on average, increases the indoor radon concentration by 100 Bq/m$^3$ [7, 8].

In big cities, water processing in large municipal systems aerates the water, which allows radon to escape, and also delays the use of water until most of the

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remaining radon has decayed [9]. Therefore, the general public using surface or processed water does not have a radon problem from their water.

In the city of Dera Ismail Khan, besides processed municipal water, a hand pump and electric motor pump are also used to extract ground water sources for drinking and house hold purposes. The dissolved radon in this water may pose health hazards due its ingestion as well as its escape into the indoor air while taking showers, washing clothes, *etc*. Although extensive data is available regarding indoor radon measurements (see, for example [10-14] and references quoted therein), limited studies have been carried out to measure waterborne radon in Pakistan [15-17]. This article deals with measurement of waterborne radon in ground water of the Dera Ismail Khan city using the pylon vacuum water degassing system (PVWDS) and CR-39 based NRPB dosimeters. The data sets obtained from active and passive devices were compared.

## MATERIALS AND METHODS

### Study area

Dera Ismail Khan is the southernmost district of the Khyber Pakhtunkhwa province of Pakistan, lying between 31° 152' North latitude and 70° 112' East longitude. The total area of the district is 7326 km$^2$.

### Climate

The area lies in the domain of hot semi-arid climate with considerable seasonal fluctuations in temperature and rainfall. The average monthly temperature of Dera Ismail Khan shows a hot period from May until September with a mean exceeding 30 °C. In winter the average monthly temperature drops below 12 °C in December and January. Rainfall is concentrated in two wet seasons, the first with a maximum in March/April and the second with a maximum in July/August. The average yearly precipitation at Dera Ismail Khan is 261 mm [18].

### Geology

The city is situated on the west bank of the Indus River. The Dera Ismail Khan basin is a part of the Lower Indus basin and is composed of alluvial sediments derived from the Indus and its tributaries [18].

Quaternary deposits which occur in the Dera Ismail Khan Plain are usually sands, silts and gravels with variable thicknesses and extent. In the Dera Ismail Khan Plain, they attain a thickness of over 300 m [19].

The major components of recharge of the groundwater aquifer in Dera Ismail Khan are sub-surface inflow of groundwater from the mountainous area, infiltration of surface runoff mainly of streams and rivers entering the area from the adjacent mountains and overland flow during heavy rains [20].

### Sampling

A total of 60 drinking water samples including the hand pump and motor pump were collected from the Dera Ismail Khan city and its outskirts. The sampling points are shown on the map (see fig. 1). Both types of samples were collected directly from the pumps in well-washed bottles which were sealed immediately. For preservation of samples concentrated $HNO_3$ (1 mL per litre of sample water) was added to each sample. The samples were collected in the month of September and October.

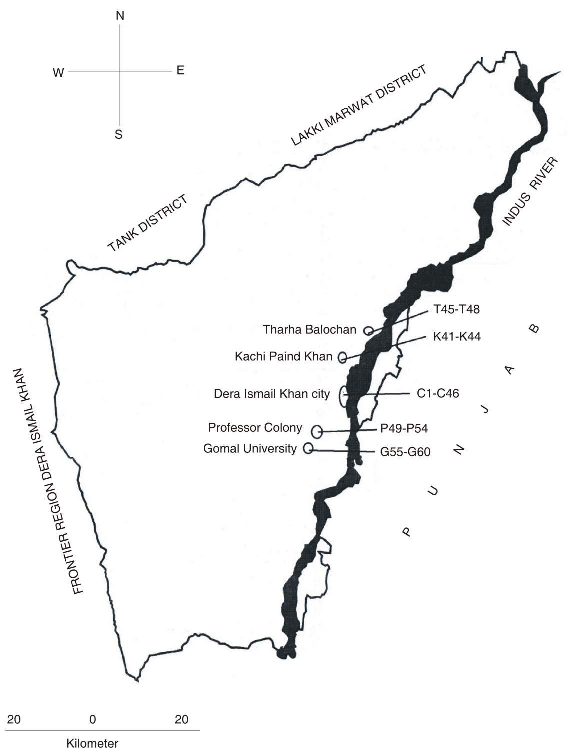


**Figure 1. Map of the Dera Ismail Khan city indicating sampling points**

## EXPERIMENTAL TECHNIQUES

### Pylon WG-1001 vacuum water degassing system

The WG-1001 vacuum water degassing system is designed to extract gases containing radon from water samples and place them in a Lucas type cell to allow measurement of the amount of radon gas present in the water.

The counting efficiency of the instrument is 0.745  0.02 cps/dps and sensitivity at equilibrium is 0.617 cps / (Bq/L). The maximum background of the instrument is 1 cpm (counts per minute), for pylon model 300A Lucas cells (manufactured by Pylon Electronics Inc., Ottawa, Canada). The lower limit of detection was estimated to be 27.4 Bq/m$^3$. The pylon AB-5 radiation monitor which measures radon ($^{222}$Rn) and thoron ($^{220}$Rn) gas, has a maximum counting rate of 10,000 cps for a 190-ml water sample.

To measure radon concentration in water samples, the background of the scintillation cell was measured for five minutes and was converted to counts per minutes (cpm). The sampling time ($T_s$) was recorded. The pump was connected to evacuate the system to a minimum of 27 inches of mercury. After disconnecting the pump, 190 ml of the water sample was transferred into the graduated cylinder and was sealed tightly. The bubbler was connected and a fine steady bubbling rate was maintained for 5 minutes. For counting, the scintillation cell was placed in the radiation monitor approximately 3.5 hours after sampling when the radon activity in the cell reached equilibrium. The counting time ($T_c$) was noted.

Radon concentration in water samples by using PVWDS was determined by the equation

$$A \quad \frac{(C \quad B)\ 1000}{F\ 3\ D\ S\ V} \qquad (1)$$

where $A$ [BqL$^{-1}$] is the $^{222}$Rn activity concentrations, $C$ [s$^{-1}$] – the gross count rate, $B$ [s$^{-1}$] – the background rate, $F$ – the cell counting efficiency (0.745 cps/dps*), $D$ – the degassing efficiency for 300A cells (0.90), $S$ – the correction for decay of radon from sampling time $T_s$ to counting time $T_c$ (0.97026), $V$ – the sample volume (190 mL), and no. 3 is the number of $\alpha$-emitters.

## Track detection technique

The radon concentrations in water samples were also measured by the particle track detection technique to support the results obtained by the pylon system. For this purpose a sheet of 500  m thickness of CR-39 track detector (supplied by Intercast, Parma, Italy) was cut into square pieces of 2  2 cm$^2$ and these were fixed in the national radiological protection board (NRPB) type dosimeters. The 500 ml water sample was put in a plastic container 27.5 cm high (volume 10.2 10$^3$ cm$^3$) having a sample surface area 369.6 cm$^2$. The dosimeters were installed in the containers which were sealed for a period of 90 days. In order to avoid the contribution of radioactive thoron gas from the sample, the dosimeters were fixed at a height greater than 25 cm from the water level [3, 21]. The detectors were exposed to a variable level of radon concentration during the exposure period because initially the radon level is zero in the chamber of the dosimeter. With the passage of time the radon activity level rises from zero to the equilibrium value. Therefore the effective exposure time of the detectors was calculated by the following relation [3]

$$T_{\text{effective}} \quad t \quad \tau(1 \quad e^{\lambda t}) \qquad (2)$$

where $t$ [d] is the total exposure length, $\lambda$ [h$^{-1}$] – the radon decay constant (7.55 10$^{-3}$h$^{-1}$), and $\tau$ [d] – the mean life of radon (5.5 d).

This correction is made in all closed systems [3]. The effective time calculated for three months exposure is 2028 hors.

After exposure the CR-39 track detectors were chemically etched at 80 °C in a 6N NaOH solution for sixteen hours and the track densities were measured.

The measured track densities were converted into radon concentrations by using the following conversion factor [21]

2.7 tracks cm$^{-2}$h$^{-1}$ = 1 kBq/m$^3$ = 1 Bq/L

## RESULTS AND DISCUSSION

Table 1 shows waterborne radon activities ($W_{Rn}$) from the collected water sample using active and passive techniques, whereas minimum, maximum and the mean values of $W_{Rn}$ with a standard deviation (SD) are listed in tab. 2.

From the measured data average values of waterborne radon concentrations have been calculated and found to be 0.041  0.015 and 0.076  0.024 Bq/L in samples taken from hand pumps and motor pumps using the pylon system whereas CR-39 based measurements yielded average values of 0.081  0.021 and 0.120  0.020 Bq/L, respectively. As may be seen in tab. 2, minimum and maximum values in hand pump water samples are 0.015 and 0.066 Bq/L using the pylon system and 0.042 and 0.125 Bq/L using CR-39 based radon detectors. In motor pump samples minimum and maximum radon concentrations are 0.021 and 0.145 Bq/L for the pylon system and 0.075 and 0.158 Bq/L in the case of CR-39 based radon detectors. The minimum value of waterborne radon has been observed in samples collected from the hand pump whilst the maximum value has been found in samples collected from motor pump water. Motor pump water samples were taken directly from the pump when the motor was on.

In Dera Ismail Khan, the water is extracted from a depth of about 14-21 meters using motor pumps whereas in the case of the hand pump water is extracted from a depth of about 9-12 meters. The hand pumps on at the bank of the river are used to pump out

* cps/dps stands for counts per second/desintegrations per second

**Table 1. Waterborne radon activities in drinking water samples of the Dera Ismail Khan city**

| Sample No. | Sample type/location | $W_{Rn}$ [BqL$^{-1}$] Pylon system | $W_{Rn}$ [Bq/L$^{-1}$] CR-39 detector | Sample No. | Sample type/location | $W_{Rn}$ [BqL$^{-1}$] Pylon system | $W_{Rn}$ [Bq/L$^{-1}$] CR-39 detector |
|---|---|---|---|---|---|---|---|
| C1 | Hand pump Halim Colony D. I. Khan | 0.048 | 0.091 | C31 | Motor pump Sheikh Yousaf | 0.072 | 0.100 |
| C2 | Hand pump from the bank of the river | 0.018 | 0.066 | C32 | Motor pump Bhatia Bazaar | 0.087 | 0.129 |
| C3 | Hand pump from the bank of the river | 0.015 | 0.050 | C33 | Motor pump Kalan Bazar | 0.090 | 0.133 |
| C4 | Hand pump from the bank of the river | 0.033 | 0.066 | C34 | Motor pump Baranabad | 0.071 | 0.112 |
| C5 | Hand pump Circular road | 0.033 | 0.062 | C35 | Motor pump Bhatia Bazaar | 0.051 | 0.108 |
| C6 | Hand pump from the bank of the rive | 0.027 | 0.042 | C36 | Motor pump Model town | 0.092 | 0.149 |
| C7 | Hand pump Muslim Bazaar | 0.039 | 0.079 | C37 | Motor pump Muslim Bazar | 0.145 | 0.158 |
| C8 | Hand pump Awan Abad | 0.033 | 0.075 | C38 | Motor pump Tank Adda | 0.079 | 0.133 |
| C9 | Hand pump Islamia colony | 0.051 | 0.083 | C39 | Motor pump Muslim bazaar | 0.088 | 0.141 |
| C10 | Hand pump Islamia colony | 0.039 | 0.087 | C40 | Motor pump Tank Adda | 0.102 | 0.145 |
| C11 | Hand pump Ghari Sadozai | 0.041 | 0.075 | K41 | Hand pump Kachi Paind Khan | 0.018 | 0.054 |
| C12 | Hand pump from the bank of the river | 0.030 | 0.058 | K42 | Hand pump Kachi Paind Khan | 0.023 | 0.058 |
| C13 | Hand pump Eid Gah road | 0.039 | 0.079 | K43 | Motor pump Kachi Paind Khan | 0.074 | 0.100 |
| C14 | Hand pump Islamia colony | 0.050 | 0.091 | K44 | Motor pump Kachi Paind Khan | 0.060 | 0.108 |
| C15 | Hand pump Muslim Bazaar | 0.050 | 0.075 | T45 | Hand pump Thatha Balochan | 0.066 | 0.094 |
| C16 | Hand pump Sardar-i-wala | 0.062 | 0.108 | T46 | Hand pump Thatha Balochan | 0.051 | 0.100 |
| C17 | Hand pump new Bannu chungi | 0.039 | 0.083 | T47 | Motor pump Thatha Balochan | 0.039 | 0.094 |
| C18 | Hand pump Wanda Baluchan | 0.052 | 0.079 | T48 | Motor pump Thatha Balochan | 0.054 | 0.100 |
| C19 | Hand pump from the bank of the river | 0.038 | 0.066 | P49 | Hand pump Professor colony | 0.057 | 0.112 |
| C20 | Hand pump Muslim Bazaar | 0.039 | 0.075 | P50 | Hand pump Professor colony | 0.056 | 0.079 |
| C21 | Motor pump Halim Colony | 0.073 | 0.116 | P51 | Hand pump Professor colony | 0.018 | 0.075 |
| C22 | Motor pump Halim Colony | 0.050 | 0.100 | P52 | Motor pump Professor colony | 0.065 | 0.108 |
| C23 | Motor pump Islamia Colony | 0.060 | 0.108 | P53 | Motor pump Professor colony | 0.102 | 0.141 |
| C24 | Motor pump Awan Abad | 0.084 | 0.120 | P54 | Motor pump Professor colony | 0.064 | 0.108 |
| C25 | Motor pump Islamia colony | 0.060 | 0.100 | G55 | Hand pump Gomal University | 0.048 | 0.125 |
| C26 | Motor pump Islamia colony | 0.077 | 0.120 | G56 | Hand pump out side Gomal University | 0.063 | 0.120 |
| C27 | Motor pump Islamia colony | 0.066 | 0.112 | G57 | Hand pump Gomal University | 0.061 | 0.120 |
| C28 | Motor pump Usman Ghni Town | 0.066 | 0.108 | G58 | Motor pump out side Gomal University | 0.116 | 0.145 |
| C29 | Motor pump Jhok Khlar | 0.093 | 0.141 | G59 | Motor Pump out side Gomal University | 0.101 | 0.137 |
| C30 | Motor pump Eid Gah road | 0.021 | 0.075 | G60 | Motor pump out side Gomal University | 0.083 | 0.141 |

**Table 2. Minimum, maximum and mean $W_{Rn}$ with standard deviation (SD) in drinking water of the Dera Ismail Khan city**

| Water source | $W_{Rn}$ [BqL$^{-1}$] pylon system | | | | $W_{Rn}$ [BqL$^{-1}$] CR-39 detector | | | |
|---|---|---|---|---|---|---|---|---|
| | Minimum | Maximum | Mean | SD | Minimum | Maximum | Mean | SD |
| Hand pump | 0.015 | 0.066 | 0.041 | 0.015 | 0.042 | 0.125 | 0.081 | 0.021 |
| Motor pump | 0.021 | 0.145 | 0.076 | 0.024 | 0.075 | 0.158 | 0.120 | 0.020 |

river water for drinking purposes. The depth at which water is pumped out by these pumps is 5-8 meters. The minimum radon concentration was found in a hand pump sample which was at on the bank of the river. In the motor pump water, the average value of the radon concentration was slightly higher as compared to the hand pump water. This may be due to the difference in depth of the two types of water wherefrom the water is extracted. Because shallow groundwater sources, like hand pumps, have a lower radon concentration due to the limited superficial water circulation, while deeper sources, like motor pumps, have a higher radon concentration due to the larger probability for interaction of water with the rock.

According to the Environmental Protection Agency (EPA) of the United States, the safe level of radon in drinking water is 11 kBq/m$^3$ or 11 Bq/L [22]. The results obtained for the drinking water of the Dera Ismail Khan city are within this recommended level.

Waterborne radon data obtained using passive and active techniques have been compared in fig. 2. A good correlation ($R^2 = 0.8292$) has been observed between the results of the passive and active techniques.

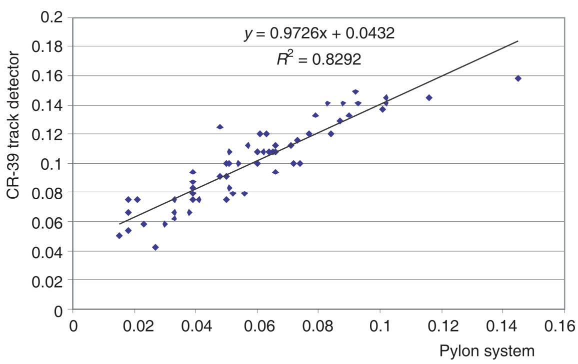


**Figure 2. Comparison of waterborne radon [BqL$^{-1}$] measured in drinking water of the Dera Ismail Khan city using pylon system and CR-39 track detector**

### Annual effective dose

The annual effective dose [mSvy$^{-1}$] received by an adult due to the ingestion of radon from drinking water has been calculated by the following equation [23].

$$AED \quad C_{\rm Rn} \quad DCF \quad L \tag{3}$$

where $C_{\rm Rn}$ [BqL$^{-1}$] is the activity concentration of radon, *DCF* [nSv/Bq] – the dose conversion factor (3.5 nSv/Bq for an adult) [24] and *L* [L] – the annual intake of water by an adult (730 L per year) [25].

The calculated values of an annual effective dose for drinking water sources are given in tab. 3. The annual effective dose measured by the pylon system is $1.058\ 10^{-4}$ and $1.949\ 10^{-4}$ mSv/y whereas CR-39 based radon detectors yielded values as $1.083\ 10^{-4}$ and $1.906\ 10^{-4}$ mSv/y, for the hand pump and motor pump water, respectively. The calculated values of the annual effective dose due to the ingested radon with water are within the recommended value of 0.1 mSv for the public [26, 27].

**Table 3. Annual effective dose expected to be received by an adult from drinking water sources in the Dera Ismail Khan city**

| Detector | Water source | Average $W_{\rm Rn}$ [BqL$^{-1}$] | Annual effective dose [mSvy$^{-1}$] $10^{-4}$ |
|---|---|---|---|
| Pylon system | Hand pump | 0.0413 | 1.055 |
| | Motor pump | 0.0762 | 1.947 |
| CR-39 | Hand pump | 0.0809 | 2.067 |
| | Motor pump | 0.1197 | 3.058 |

## CONCLUSIONS

Waterborne radon activity has been measured in drinking water of the Dera Ismail Khan city using active and passive techniques. The results obtained have been intercompared and are found to be in good agreement. Relatively higher values of radon concentration are found in water extracted with motor pumps. Nevertheless, measured values of waterborne radon in all the studied water samples using active and passive techniques are within the world wide recommended safe limit of 11 Bq/L. The annual effective dose received by the inhabitants due to the ingested radon from drinking water measured by both active and passive techniques has also been found to be very considerably less than the recommended dose of 0.1 mSv. Therefore, to conclude, drinking water of the Dera Ismail Khan city is safe to use for drinking and other household purposes.

## AUTHOR CONTRIBUTIONS

Samples were collected by R. Tahseen. Experiments were carried out by Matiullah, R. Tahseen, and T. Nasir. All authors analysed and discussed the results. The manuscript was written by T. Nasir, M. Rafique, and Matiullah. The figures were prepared by T. Nasir.

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Received on April 23, 2015
Accepted on May 29, 2015

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**Табасум НАСИР, МАТИУЛАХ, Мухамад РАФИК, Рубин ТАХСИН**

## МЕРЕЊА РАДОНА ОСЛОБОЂЕНОГ ИЗ ПИЈАЋЕ ВОДЕ У ГРАДУ ДЕРА ИСМАИЛ КАН ПРИМЕНОМ АКТИВНИХ И ПАСИВНИХ ПОСТУПАКА

Сматра се да је вода из земљишта други највећи извор концентрације радона у унутрашњости просторија. Стога је мерење радона ослобођеног из воде још увек интерес многих истраживача. Главни циљ овог рада је проучавање активности радона ослобођеног из воде у граду Дера Исмаил Кан. У том смислу, узорци воде су прикупљани са различитих локација града из којих је радон мерен пилонским вакуумским системом са дегазирањем воде и детекторима радона заснованим на CR-39. Пилон систем је као резултат мерења дао активности за узорке прикупљане ручним и моторним пумпама у границама 0.015-0.066 Bq/L и 0.021-0.145 Bq/L, са средњим вредностима 0.041 Bq/L и 0.076 0.024 Bq/L, респективно. Процењена годишња доза услед ингестије радона пијаћом водом, добијена употребом пилонског система и детектора заснованих на CR-39, за ручне и моторне пумпе, износи 1.055 $10^{-4}$ mSv и 1.947 $^{-4}$ mSv и 2.067 $^{-4}$ mSv и 3.058 $^{-4}$ mSv, респективно. Концентрација радона ослобођеног из воде и процењена годишња ефективна доза настала њеном употребом, налазе се у препорученим безбедним границама.

*Кључне речи: вода за пиће, пилон систем, CR-39, концентрација радона, годишња ефективна доза*