Assessment of Seasonal Variation of Indoor Radon Level in Dwellings of Some Districts of Azad Kashmir, Pakistan

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Key Words
Indoor radon • CR-39-based radon dosimeters • Seasonal correction factor • Radon doses • Azad Kashmir

Abstract
Measurements of indoor radon concentrations in 200 dwellings of four districts of Azad Kashmir have been carried out using CR-39-based radon dosimeters. Indoor radon levels were calculated for four seasons (i.e. spring, summer, autumn and winter) in Muzaffarabad, Hattian, Neelum and Poonch districts. Maximum value of radon concentration (398 ± 2 Bq m⁻³) has been found in Muzaffarabad district (in bedrooms) and minimum value (23 ± 9 Bq m⁻³) is reported for Hattian district (in living rooms). Elevated values of radon levels have been found in winter, whilst lower values are observed in summer season. Seasonal correction factors calculated for spring, summer, autumn and winter seasons were found to be 1.02 ± 0.91, 0.86 ± 0.77, 0.98 ± 0.92 and 1.14 ± 1.04, respectively. Measured values for winter/spring, winter/summer and winter/autumn radon ratios were found as 1.11 ± 1.28, 1.33 ± 1.21 and 1.15 ± 1.17. Radon doses have been calculated and yearly mean effective dose has been found 2.52 ± 1.22 mSv, which is less than the lower limit of the recommended action level 3–10 mSv.

Introduction

²²²Rn is a naturally occurring noble gas resulting from the decay of ²²⁶Ra, which is derived from decay series of uranium. Uranium is ubiquitous in nature since from the formation of the planet, it is found in rocks, soil and water [1]. It seeps from the ground into atmosphere where it mixes with fresh air. Its initial concentration is too low to
be of concern; however, inside the buildings, it gets trapped in close rooms resulting in higher values of concentrations. The health risk associated with prolonged exposure to radon increases the risk of developing lung cancer. Since radon is an inert gas, it is probably exhaled by the lungs before its decay. Radon itself is not a cause of threat; however, its daughter products with their short half-lives emit alpha particles, which cause more damage than radon gas. Radon decay products are charged heavy metals and can be inhaled as attachments to atmospheric particles like dust, smoke or biological entities [2,3]. These particles within the respiratory system adhere to the mucus lining of the alveoli or bronchial regions. Adherence can increase the probability of decay inside the lungs. As a result of decay, cellular mutations start in the lungs [4,5].

Significant variations of indoor radon level have been seen over time. Even a change by a factor of two to three times over a 1-day period has been seen and variations from season to season can be even larger [6]. Higher radon levels are usually observed during winter months [7]. As a result, a long-term measurement period will give a much better indication of the annual average radon concentration than measurements of shorter duration. Therefore, seasonal correction factor (SCF) has to be applied in order to determine annual average value of radon from the indoor radon levels measured for a short period of time [8–11].

Several studies have been conducted at national and international levels to measure and set up remedial actions against indoor radon concentrations. In the past two decades, many individuals in Pakistan have tried to address the subject in specific regions of Pakistan [12–28].

This study deals with the measurement of the seasonal variation of indoor radon level and to calculate the SCF for four districts of Azad Kashmir. This study is a continuation of our previous published work. It is a step forward for setting the baseline data at radon Atlas for this part of world [18,19].

**Area Under Study**

This study has been carried out in four districts of Azad Kashmir, namely Muzaffarabad, Hattian, Neelum and Poonch (Figure 1). The first three districts were initially part of Muzaffarabad district and therefore are interconnected, whilst district Poonch district is separated from these through another district called Bagh. Muzaffarabad city is the capital of state of the Azad Kashmir, NE Pakistan (Figure 1). It is located at a latitude of 34°20'16"N and a longitude of 73°30'33"E. Located at an altitude of 1250 m above the sea level, it is surrounded by mountains and lies at a distance of approximately 140 km from Islamabad and 80 km from Abbottabad. Poonch district lies in the sub-Himalayas of northeast Pakistan. It is situated at 90 km from Islamabad via Azad Pattan. Its altitudes vary from 1646 to 1981 m.

**Climatic Conditions**

Poonch district lies in a humid region. It is within the reach of the monsoon. Its climate varies from tropical to temperate. Winter is severely cold and summer slightly hot. Mean annual rainfall varies from 2500 to 2850 mm, and maximum rainfall occurs in the months of June, July and August. Maximum temperature varies from 31°C to 32°C in the month of June. Climate of Hattian district is tropical to subhumid. Maximum humidity occurs in the months of June, July and August. Average temperature varies from a maximum of 35°C to 1°C. In Muzaffarabad and Neelum districts, winter is very cold and summer hot. In the summer, rain showers are common, whereas in winter, occasionally snowfall occurs. Heavy rainfall takes place during the months of July and August and the maximum humidity is usually recorded during this period.

**Building Characteristics**

In the villages of all four districts, most of the houses are made up of mud and stones with timber or steel sheet made roofs, whilst majority of the houses surveyed in city areas are built with bricks made of cement and clay and with blocks made of cement and limestone–dolomite aggregate. The roofs of the houses were made of cement, sand and steel. There was poor ventilation system in the houses surveyed in Muzaffarabad district. The majority of houses surveyed have one or no window in rooms. In other districts, houses have proper ventilation system, when compared to Muzaffarabad district houses.
this study. Measurements of radon concentration in bedrooms and living rooms were made at the ground floor of all the houses. Usually, there was no difference of physical or structural materials of bed rooms and living rooms. The main difference that we have noted during our survey was that living rooms were large in size and have more windows for ventilation purposes compared to bedrooms of the studied area.

CR-39-based radon dosimeters were installed in bedrooms and living rooms and study was carried out from March 1, 2008 to February 28, 2009. The whole study was divided into four parts to cover 1 complete year. Due to the natural occurrence of four seasons (i.e. spring, summer, autumn, winter) in this part of the world, it was reasonable to install radon dosimeters on season-based pattern. Spring season begins at the start of March and ends in May, summer season span over June to August, autumn starts from September and ends at the start of November and winter starts in December and ends in February.

Large sheets of CR-39 detectors were cut into small strips (having dimensions $3 \times 3 \times 1.14 \text{ cm}^3$) and placed in a box-type dosimeter with dimensions $3 \times 3 \times 1.14 \text{ cm}^3$ (Figure 2). Two detector strips were placed at the two opposite walls of the holder. The design of this type of radon detector ensures that all the aerosols and radon decay products are kept outside and only radon diffuses into the sensitive volume of the chamber. The detectors were placed at a height of about 1.524 m from the ground in the bedrooms and living rooms of each house (all in the ground floor storey). After 90 days of indoor radon exposure, CR-39 detectors were retrieved and etched in a 6-M NaOH solution at 70°C for 9 h. The detectors were washed in ultrasonic cleaner bath. Tracks were counted under optical microscope at a magnification of 400×. After the background correction, track densities were related to the indoor radon concentrations (Bq·m$^{-3}$) using a calibration factor of 0.0092 tracks·cm$^{-2}$·h$^{-1}$ = 1 Bq·m$^{-3}$ and the average value of the two detector strips was taken [13].

In the process of detector installation, information about time spent in living room and bedrooms were obtained from house occupants. These data revealed that occupants spent ~60% of their indoor time in bedroom and 40% time in living room. From the data obtained,
weighted average annual arithmetic mean for each house was calculated using the following formula:

\[
\text{体重平均 radon concentration} = (0.4 \times \text{living room} + 0.6 \times \text{bedroom}) \text{ indoor radon concentration}
\]

After conversion of radon concentrations in bedrooms and living rooms into weighted indoor radon levels, SCF and mean annual effective doses were calculated by making use of the weighted indoor radon levels [28].

### Results and Discussion

As discussed earlier, indoor radon levels have been measured in 200 houses of four districts (50 houses in each district) of Azad Kashmir. Measurements have been made separately for each season (spring, summer, autumn and winter) covering 1 complete year. Results are shown in Tables 1 and 2.

As seen in Table 1, indoor radon concentration levels in Muzaffarabad district vary from 38 ± 9 to 398 ± 2 Bq·m⁻³ in bedrooms and from 31 ± 10 to 302 ± 3 Bq·m⁻³ in living rooms. In the Hattian district, the variation in the indoor radon concentration level ranged from 27 ± 2 Bq·m⁻³ to 201 ± 4 Bq·m⁻³ in bedrooms and from 23 ± 9 to 179 ± 3 Bq·m⁻³ in living rooms. In the Neelum district,

![Diagram of the box-type radon detector](image)

**Fig. 2.** Schematic representation of the box-type radon detector used for the measurement of indoor radon in this study.

### Table 1. Measured minimum and maximum weighted average indoor radon concentration levels (Bq·m⁻³) in different seasons in four districts of Azad Kashmir

<table>
<thead>
<tr>
<th>Season</th>
<th>Muzaffarabad</th>
<th>Hattian</th>
<th>Neelum Valley</th>
<th>Poonch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bedroom</td>
<td>Living room</td>
<td>Bedroom</td>
<td>Living room</td>
</tr>
<tr>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
<tr>
<td>Spring</td>
<td>42 ± 6</td>
<td>313 ± 4</td>
<td>36 ± 8</td>
<td>287 ± 4</td>
</tr>
<tr>
<td>Summer</td>
<td>38 ± 9</td>
<td>188 ± 7</td>
<td>31 ± 9</td>
<td>144 ± 7</td>
</tr>
<tr>
<td>Autumn</td>
<td>41 ± 8</td>
<td>218 ± 5</td>
<td>38 ± 7</td>
<td>173 ± 6</td>
</tr>
<tr>
<td>Winter</td>
<td>49 ± 5</td>
<td>398 ± 2</td>
<td>42 ± 5</td>
<td>302 ± 3</td>
</tr>
</tbody>
</table>

### Table 2. Measured mean indoor radon concentration levels (Bq·m⁻³) and SCFs in four districts of Azad Kashmir

<table>
<thead>
<tr>
<th>Districts</th>
<th>Mean radon concentration (Bq·m⁻³) in different seasons</th>
<th>Yearly average radon concentration</th>
<th>Seasonal correction factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spring</td>
<td>Summer</td>
<td>Autumn</td>
</tr>
<tr>
<td>Muzaffarabad</td>
<td>112 ± 41</td>
<td>97 ± 38</td>
<td>107 ± 39</td>
</tr>
<tr>
<td>Hattian</td>
<td>101 ± 31</td>
<td>84 ± 27</td>
<td>99 ± 43</td>
</tr>
<tr>
<td>Neelum Valley</td>
<td>108 ± 38</td>
<td>89 ± 41</td>
<td>94 ± 41</td>
</tr>
<tr>
<td>Poonch</td>
<td>88 ± 29</td>
<td>74 ± 25</td>
<td>94 ± 37</td>
</tr>
<tr>
<td>Seasonal average</td>
<td>102 ± 37</td>
<td>86 ± 35</td>
<td>98 ± 39</td>
</tr>
</tbody>
</table>
indoor radon variations ranged from \(34 \pm 7\) to \(249 \pm 2\) Bq m\(^{-3}\) in bedrooms and from \(31 \pm 8\) to \(223 \pm 3\) Bq m\(^{-3}\) in living rooms. In the Poonch district, indoor radon concentration levels varied from \(27 \pm 6\) to \(196 \pm 4\) Bq m\(^{-3}\) and from \(25 \pm 7\) to \(202 \pm 2\) Bq m\(^{-3}\) in the bedrooms and living rooms, respectively.

For bedrooms, minimum value of radon concentration was found to be \(27 \pm 9\) Bq m\(^{-3}\) in bedrooms of Hattian and Poonch districts in the summer, whereas maximum value was found as \(398 \pm 2\) Bq m\(^{-3}\) in Muzaffarabad district in the winter. For living rooms, the minimum value of radon concentration was found as \(23 \pm 9\) Bq m\(^{-3}\) in the summer season of Hattian district and the maximum value was found as \(302 \pm 3\) Bq m\(^{-3}\) in the winter season of Muzaffarabad district. The highest and lowest values of indoor radon concentrations (Table 2) were observed in the winter and summer seasons, respectively.

Yearly average radon concentrations (Table 2) for Muzaffarabad, Hattian, Neelum and Poonch districts were found as \(110 \pm 41\), \(98 \pm 33\), \(102 \pm 37\) and \(90 \pm 29\) Bq m\(^{-3}\), respectively. Overall seasonal average of the area surveyed was found to be \(100 \pm 36\) Bq m\(^{-3}\).

**Dose Estimation**

From several epidemiological studies and physical dosimetry, the range of dose conversion factors for radon varies from 6 to 15 nSv (Bq h m\(^{-3}\))\(^{-1}\). For the estimation of average effective dose \((H)\) (mSv y\(^{-1}\)) to the inhabitants of study area due to the indoor radon and its progeny, the following equation UNSCEAR [28] was adopted:

\[
H = C \times F \times O \times T \times D
\]

where \(C\) stands for the weighted average indoor radon concentration in Bq m\(^{-3}\), \(F\) (0.4, taken for indoor inhabitants) for equilibrium equivalent concentration factor, \(O\) for occupancy factor (0.8 as taken in UNSCEAR 2000 report), \(T\) for time (8760 h y\(^{-1}\)) and \(D\) for dose conversion factor (9 nSv h\(^{-1}\) Bq m\(^{-3}\))\(^{-1}\).

From Figures 3 and 4, we can see that radon doses ranged from \(2.28 \pm 1.11\) to \(2.77 \pm 1.31\) mSv y\(^{-1}\). Using UNSCEAR 2000 conversion factor, mean annual effective doses of \(2.77 \pm 1.31\), \(2.47 \pm 1.19\), \(2.57 \pm 1.22\) and \(2.28 \pm 1.11\) mSv y\(^{-1}\) for Muzaffarabad, Hattian, Neelum and Poonch districts have been found. The highest values for radon doses are reported for Muzaffarabad district whilst the lowest for Poonch district. From Figure 3, it can be seen that annual mean effective doses have higher values for winter compared to summer.

Differences in the indoor radon levels have been seen in all four surveyed districts. Higher levels of indoor radon levels are seen in Muzaffarabad and Neelum districts. The reason of higher values in Muzaffarabad district might be due to the nature of building material used and the geology of the dwellings underlying soil. Gunby et al. [29] showed that underlying geology is a factor determining the average radon levels. The highest levels of indoor radon were associated with Granite reserves underlying the soil. Several other studies have established higher radon levels with geology of particular regions [30–32]. There are large reserves of granite and marbles in Muzaffarabad district. Soil characteristics may also affect radon transportation from the source into houses. As a relationship developed by Dudney and Hawthorne [33] through analysis of various variances test shows that the drainage and slope of surface soil may be significantly associated with indoor radon levels. On classifying the soil in Muzaffarabad district area, most of the soils were found to contain high contents of sandy-clay and sandy-silty clay with an average density of 7.65%. Most of the foundation placed on these soils, absorbs water probably due to the high water level in the area. The soils on the steep slopes are mainly composed of sand silt, clay and gravels, as we move towards valleys, since most of the buildings in Muzaffarabad district have been constructed on the slopes and the water drains through the soils underlying the foundation of dwellings. Other reasons for higher values in Muzaffarabad are poor ventilation of houses; houses are constructed very close to each other and the material used as countertop like granite and marble is often used in houses as a decorative material. On the other hand, houses are scattered in Poonch district and to some extent in Hattian and Neelum.

**Seasonal Correction Factor**

The SCF is basically a numerical multiplier converting a short-term radon concentration measurement to an annual
average concentration [34]. The SCF was calculated by dividing the arithmetic mean, calculated for each cycle (i.e. spring, summer, autumn and winter), by the yearly averaged radon concentration. Overall SCFs (Table 2) came out to be 1.02 ± 0.91, 0.86 ± 0.77, 0.98 ± 0.92 and 1.14 ± 1.04 for spring, summer, autumn and winter seasons, respectively. Measured winter/spring, winter/summer and winter/autumn radon levels range from 1.07 to 1.19, 1.27 to 1.43 and 1.09 to 1.25 with an average value of 1.11 ± 1.28, 1.33 ± 1.21 and 1.15 ± 1.17, respectively. Winter/summer ratio (Figure 5) of indoor radon is highest compared to winter-to-spring and winter-to-autumn ratios.

**Comparison of Survey Results**

Results obtained from this survey have been compared with data already available in literature. The yearly average indoor radon concentration calculated on the basis of the measurements carried out in this survey is 100 ± 36 Bq·m⁻³. This is higher than the values reported for many other countries, like in the case of United States and United Kingdom, the reported values of radon arithmetic mean concentration are about 46.25 and 20 Bq·m⁻³ [35]. Similarly, values reported for some parts of India, namely Himachal Pradesh (45 Bq·m⁻³), Assam (42 Bq·m⁻³) and Meghalaya (68 Bq·m⁻³) [36] are all lower than the one reported in this study. In Pakistan, for North West Frontier Province, the reported value for average indoor radon levels is ~65 Bq·m⁻³ [16]. The maximum arithmetic mean previously identified in Pakistan (111 Bq·m⁻³) has been reported for Skardu City [37].

As part of the study, SCF was also calculated and compared with the correction factors reported for other countries of the world. SCFs calculated for this study were found as 1.02 ± 0.91, 0.86 ± 0.77, 0.98 ± 0.92 and 1.14 ± 1.04 for spring, summer, autumn and winter seasons, respectively. On the other hand, in other studies for example, Grainger et al. [11] have reported SCFs of 1.17 and 0.85 for summer and winter in the Isle of Man, UK. For France, Baysson et al. [9] have reported the SCFs of 0.93, 0.99, 1.075 and 0.99 for winter, spring, summer and autumn, respectively. In Pakistan, Faheem et al. [38] have reported SCFs of 1.14, 0.89, 0.91 and 1.15, which were reported for the spring, winter, autumn and summer seasons, respectively, and Rahman et al. [17] reported 1.15, 0.89, 0.91 and 1.15 for spring, winter, autumn and summer seasons, respectively. SCFs calculated for this study differ from the above-mentioned studies; this might be due to differences in the climatic, topographic and geological conditions.
conditions of Azad Kashmir compared to other areas of the study.

Conclusion

Indoor radon concentrations have been measured for a complete year in four cycles (i.e. spring, summer, autumn and winter seasons). Maximum radon concentration has been found in Muzaffarabad district (in bedrooms) and minimum value is reported for Hattian district (in living rooms). Elevated values of radon levels have been found in winter, whilst lower values are seen in summer season. SCF has been calculated and their usage is recommended for future short-term radon measurement in study area. Radon doses have been calculated and yearly mean effective dose has been found to be 2.52 mSv·y⁻¹, which is less than the lower limit of the recommended action level (3–10 mSv).

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