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# A Study of Groundwater Radon Concentrations in Punjab and Himachal Pradesh States, India

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**Key Words**
Radon · Alpha-Scintillometry · Groundwater · Ingestion

**Abstract**
In this paper, the results of radon concentrations in the drinking water in some areas of Punjab and Himachal Pradesh are presented. Samples were collected from the hand-pumps, tube-wells and natural springs, which are the major sources of drinking water in these areas. Radon concentration values in drinking water showed a wide variation depending on its source and location. The radon concentration values in hand-pump drawn groundwater have been found to be higher than the values from other sources. The recorded radon concentration in these samples has been found to vary from $1.0 \pm 0.3$ to $48.0 \pm 2.2\,\mathrm{Bq{\cdot}L^{-1}}$. The radon concentration has also been measured in some thermal springs and these values have been found to be quite a lot higher than from other sources of ground water. Mineral water has the minimum radon concentration compared with groundwater sources.

## Introduction

Natural water contains dissolved radon from the uranium series present in soil and rocks. Dissolved radon may be released from the water and can increase airborne radon concentration [1]. Radon in water may therefore present dual pathways of exposure to individuals, through drinking water and inhalation of radon released from water [2]. Significant contribution to the radon concentrations in houses can come from groundwater sources. The health risks which are associated with the inhalation and ingestion of radon and its progeny have been well documented [3]. The two diseases of principal concern associated with radon are stomach cancer (from ingestion) and lung cancer (from inhalation) [4]. In the light of potential hazards attributed to long-term use of water rich in radon, the interest in the study of $^{222}$Rn in groundwater has increased tremendously. Approximately, 1–7% of lung cancer fatalities in the USA have been attributed to indoor radon derived from groundwater [5]. As $^{226}$Ra decays, its gaseous daughter product $^{222}$Rn diffuses into the pore water of rock formation. Once in contact with groundwater, it may migrate over some distances, which are limited by its relatively short half-life. Nevertheless, it has a low solubility in water,


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making it prone to de-gassing from water in contact with air. A worldwide survey of groundwater indicated a $^{222}Rn$ mean concentration of about 183 Bq·L$^{-1}$ [6]. A recommended limit of radon in tap water is not yet established, but the proposed limit is 150 Bq·L$^{-1}$ [7].

Most of the radon that enters a building comes directly from soil that is in contact with or beneath the basement or foundations. Radon is also found in well water and will enter a home whenever this water is used. In many situations such as showering, washing clothes and flushing toilets, radon is released from the water and mixes with the indoor air. Thus, radon from water contributes to the total inhalation risk associated with radon in indoor air. In addition to this, drinking water contains dissolved radon and the radiation emitted by radon and its radioactive decay products exposes sensitive cells in the stomach as well as other organs once it is absorbed into the bloodstream. Although radon in drinking water does not pose a direct health risk [2], the main concern is that the levels of radon in indoor air of dwellings can be enhanced partially by radon derived from the water supply [8]. High radon concentration has been reported in the waters of Garhwal and Siwalik Himalayas and the underground waters of Doon valley [9,10].

This paper presents the results of measurements of radon in the ground water of wide areas of the Punjab and Himachal Pradesh States of India. In this study efforts were made to collect the samples from the various sources of groundwater, which are the water sources for large populations in these states. The water samples were collected from the various sources like hand-pumps, tube-wells and the submersible pumps, through which the groundwater is being drawn directly from different depths. The tube-well and submersibles are the motor driven pumps drawing the groundwater directly. The purpose of this study is to investigate the radon concentration levels of groundwater being used for drinking as potable water and to determine the health hazards, if any, to the population groups of Himachal Pradesh and Punjab States, India.

## Methods

The methodology used for radon estimation was scintillometry using silver-activated zinc sulphide phosphor, ZnS (Ag), as the scintillation material. Water samples were collected from various sources in some districts of Punjab and Himachal Pradesh States. An Alpha-Scintillometer (GBH 2002) with Lucas cell assembly (International Environmental Consultancy, Germany) was used to record alpha counts from 1 L of water over an interval of 10 min. Radon gas present in the water was sucked by a pump connected to a radon bubbler with an extraction efficiency of more than 90%. The electronic digital counter recorded the alpha counts and the radon concentration in the water was measured by using the calibration constant: 10 counts = 1 Bq·L$^{-1}$. The detection limit for the Lucas cells used in the Alpha-Scintillometer is 0.02 Bq·L$^{-1}$.

## Results

Groundwater is the major source of drinking water in the states of Punjab and Himachal Pradesh, where the commonly used sources are tap water supply schemes, hand-pumps, natural springs and thermal springs. Radon concentrations from different sources of drinking water used by the residents in different cities, towns and villages of Amritsar, Gurdaspur, Hoshiarpur and Bathinda districts of Punjab state are summarised in Table 1. The commonly used sources in these four districts are hand-pumps, submersibles and water supply schemes. As can be observed from Table 1, the maximum value of radon concentration was found in groundwater drawn by hand-pumps and the minimum value in water supplied through pipes after storage in water tanks (water supplies). The radon concentration in hand-pump drawn water samples lies between 2.7–8.8 Bq·L$^{-1}$, tube-well water between 2.4–7.3 Bq·L$^{-1}$ and municipal water supply sources between 2.2–5.8 Bq·L$^{-1}$.

The recorded values of radon concentration from different water sources of Kangra, Hamirpur, Mandi and Kullu districts of Himachal Pradesh using Alpha-Scintillometer are summarised in Table 2. Radon activities in groundwater samples varied from $1.0 \pm 0.3$ to $653.5 \pm 8.0$ Bq·L$^{-1}$. The maximum value of radon concentration was found in groundwater from thermal springs and the minimum value was observed in the piped water supplies. The highest value of radon concentration was recorded in thermal spring K-III at Kasol, $653.5 \pm 8.0$ Bq·L$^{-1}$ which is in Kullu district of Himachal Pradesh. Although the radon concentration in hand-pump drawn water in this district shows variation from $9.2 \pm 1.0$ to $48.0 \pm 2.2$ Bq·L$^{-1}$, a natural spring in Kalath shows radon concentration value of $63.9 \pm 2.5$ Bq·L$^{-1}$, this may be particularly due to its flow through the gneiss type of the rock formations in this area. In this district the rock types are generally phyllite, slate, schists and

**Table 1.** Radon concentration from different sources of groundwater in Amritsar, Gurdaspur, Hoshiarpur and Bathinda districts of Punjab

| Source no. | Place | Source | Radon conc. ($Bq{\cdot}L^{-1}$) |
|---|---|---|---|
| *Amritsar district* | | | |
| 1. | Verka town | Hand-Pump | $6.1 \pm 0.8$* |
| 2. | Kathu Nangal | Hand-Pump | $5.2 \pm 0.7$ |
| 3. | Jantipur | Hand-Pump | $7.3 \pm 0.8$ |
| 4. | Chheharta | Hand-Pump | $5.1 \pm 0.7$ |
| 5. | Dashmesh Avenue | Hand-Pump | $7.0 \pm 0.8$ |
| | | Water supply | $6.0 \pm 0.8$ |
| 6. | Guru Nanak Dev University campus | Tube-well | $3.7 \pm 0.6$ |
| 7. | Putligarh | Submersible Pump | $5.3 \pm 0.7$ |
| 8. | Railway station | Hand-Pump | $3.9 \pm 0.6$ |
| 9. | Ranjit Avenue | Hand-Pump | $4.6 \pm 0.7$ |
| 10. | Hall Bazar | Submersible Pump | $3.4 \pm 0.6$ |
| 11. | Guru Ramdas Bazar | Submersible Pump | $3.5 \pm 0.6$ |
| 12. | Jail Road | Hand-Pump | $5.5 \pm 0.5$ |
| 13. | Heir village | Submersible Pump | $6.1 \pm 0.8$ |
| 14. | Nangli | Submersible Pump | $4.8 \pm 0.7$ |
| 15. | Bal village | Tube-well | $4.7 \pm 0.7$ |
| 16. | Pandori Varaich | Hand-Pump | $6.6 \pm 0.8$ |
| 17. | Daburji | Hand-Pump | $4.7 \pm 0.7$ |
| 18. | Kad-Gill | Hand-Pump | $6.1 \pm 0.8$ |
| 19. | Tarn-Taran | Hand-Pump | $3.7 \pm 0.6$ |
| 20. | Kaironwaal | Hand-Pump | $3.7 \pm 0.6$ |
| 21. | Chabaal | Hand-Pump | $4.0 \pm 0.6$ |
| 22. | Baba Budha ji | Submersible Pump | $4.4 \pm 0.7$ |
| *Gurdaspur district* | | | |
| 23. | Gurdaspur City | Hand-pump | $8.8 \pm 0.9$ |
| 24. | Batala town | Hand-pump | $3.3 \pm 0.6$ |
| | | Water supply | $3.0 \pm 0.5$ |
| | | Tube-well | $3.5 \pm 0.6$ |
| 25. | Dhariwal town | Hand-pump | $6.4 \pm 0.8$ |
| | | Water supply | $5.3 \pm 0.7$ |
| | | Tube-well | $4.0 \pm 0.6$ |
| 26. | Dinanagar town | Hand-pump | $8.6 \pm 0.9$ |
| | | Water supply | $5.8 \pm 0.7$ |
| 27. | Bariar village | Hand-pump | $6.0 \pm 0.8$ |
| | | Tube-well | $5.2 \pm 0.7$ |
| | | Water supply | $4.0 \pm 0.6$ |
| 28. | Pathankot City | Hand-pump | $3.3 \pm 0.6$ |
| 29. | Dinanagar | Hand-pump | $8.8 \pm 0.9$ |
| *Hoshiarpur district* | | | |
| 30. | Aadampur town | Hand-pump | $5.4 \pm 0.7$ |
| | | Water supply | $3.3 \pm 0.6$ |
| 31. | Khurdpur village | Hand-pump | $3.3 \pm 0.6$ |
| | | Tube-well | $2.8 \pm 0.5$ |
| | | Water supply | $2.2 \pm 0.5$ |
| 32. | Fatehpur village | Hand-pump | $4.4 \pm 0.7$ |
| | | Tube-well | $3.3 \pm 0.6$ |
| | | Water supply | $2.2 \pm 0.5$ |
| 33. | Nasrala village | Hand-pump | $7.8 \pm 0.9$ |
| | Water supply | $4.4 \pm 0.7$ | |
| 34. | Piplanwala village | Hand-pump | $7.9 \pm 0.9$ |
| | | Tube-well | $5.3 \pm 0.7$ |
| | | Water supply | $4.9 \pm 0.7$ |
| *Bathinda district* | | | |
| 35. | Gobindpur village | Hand-pump | $4.3 \pm 0.7$ |
| | | Tube-well | $5.5 \pm 0.7$ |
| 36. | Bibiwala village | Hand-pump | $2.7 \pm 0.5$ |

**Table 1.** continued

| Source no. | Place | Source | Radon conc. ($Bq{\cdot}L^{-1}$) |
|---|---|---|---|
| 37. | Bhucho Khurd village | Hand-pump | $3.4 \pm 0.6$ |
| 38. | Bhucho Kalan village | Hand-pump | $4.6 \pm 0.7$ |
| 39. | Thermal colony (Bathinda) | Tube Well | $2.4 \pm 0.5$ |
| 40. | NFL colony | Hand-pump | $4.2 \pm 0.6$ |
| | | Storage tank | $2.0 \pm 0.4$ |
| 41. | Thermal Colony | Hand-pump | $5.0 \pm 0.7$ |
| | (Lehra Mohabat) | Tube-well | $3.0 \pm 0.5$ |
| 42. | Pitho Village | Hand-pump | $3.3 \pm 0.6$ |
| | | Tube-well | $4.1 \pm 0.6$ |
| 43. | Rampura Mandi | Hand-pump | $4.0 \pm 0.6$ |
| | | Tube-well | $2.9 \pm 0.5$ |
| 44. | Bagrari | Tube-well | $5.2 \pm 0.7$ |
| 45. | Gunaana-Mandi | – | $5.8 \pm 0.8$ |
| 46. | Bathinda | Water supply | $6.0 \pm 0.8$ |
| 47. | Kot-Samira | – | $5.8 \pm 0.8$ |
| 48. | Kot-Fata | Tube Well | $3.7 \pm 0.6$ |
| 49. | Maur | Hand-pump | $7.6 \pm 0.9$ |
| 50. | Bhai desa | Hand-pump | $8.0 \pm 0.9$ |
| 51. | Lahran sodaan | Hand-pump | $4.1 \pm 0.6$ |
| 52. | GTB Nagar | Hand-pump | $5.3 \pm 0.7$ |
| 53. | Kheta basti | Hand-pump | $4.6 \pm 0.7$ |
| 54. | Bulada wal | Hand-pump | $5.3 \pm 0.7$ |
| 55. | STS Nagar | – | $5.7 \pm 0.8$ |

*Statistical counting error – 1σ.

granites. Even the radioactive minerals occur in the massive quartzite near Chhinjra and Jari in the Parbati Thela in the Garsah valley. However in the near by Mandi district of Himachal Pradesh, the radon concentration in hand-pump drawn water samples lies between $11.0 \pm 1.0$ to $26.6 \pm 1.6\,Bq{\cdot}L^{-1}$, whereas the natural springs flowing in this zone have been found to have maximum value of $6.4 \pm 0.8\,Bq{\cdot}L^{-1}$. This may be due to their flow through non granitic formations. In the Kangra district the maximum value of radon concentration was found in groundwater drawn by hand-pump at Ghurkari, i.e. $48.4 \pm 2.2\,Bq{\cdot}L^{-1}$ whereas the minimum value of $4.4 \pm 0.7\,Bq{\cdot}L^{-1}$ was in natural flowing water at Tirlokpur. Most of the water samples have been collected from the hand-pump, as this is the main source of drinking water in Himachal Pradish. The rock types commonly seen in these districts are shale, clay and sandstones also the phyllites, schists and limestones. In the Hamirpur district the maximum value of radon concentration was observed in groundwater drawn by hand-pump at Neri village, i.e. $22.2 \pm 1.5\,Bq{\cdot}L^{-1}$, where as the minimum value of $1.0 \pm 0.3\,Bq{\cdot}L^{-1}$ as usual, was found in the water supply of Nukhel village. All these measurements of groundwater radon concentration in the Punjab and Himachal Pradesh

**Table 2.** Radon concentration from different sources of groundwater in Kangra, Hamirpur, Mandi and Kullu districts of Himachal Pradesh

| Source no. | Place | Source | Radon conc. ($Bq \cdot L^{-1}$) |
|---|---|---|---|
| Kangra district | | | |
| 1. | Upper Drang | Hand-pump | 35.7 ± 1.9* |
| 2. | Nagrota | Hand-pump | 46.7 ± 2.2 |
| 3. | Ghurkari | Hand-pump | 48.4 ± 2.2 |
| 4. | Raite | Natural spring | 10.8 ± 1.0 |
| 5. | Chhatri | Hand-pump | 35.7 ± 1.9 |
| 6. | Tirlokpur | Natural flowing water | 4.4 ± 0.7 |
| 7. | Pirhar | Hand-pump | 10.3 ± 1.0 |
| 8. | Baghni | Hand-pump | 13.3 ± 1.1 |
| 9. | Jassure | Hand-pump | 17.4 ± 1.3 |
| 10. | Kandwal | Hand-pump | 12.8 ± 1.1 |
| *Hamirpur district* | | | |
| 11. | Nukhel | Water supply | 1.0 ± 0.3 |
| | | Well | 4.8 ± 0.7 |
| 12. | Galot | Water supply | 2.3 ± 0.5 |
| | | Hand-pump | 11.3 ± 1.1 |
| 13. | Nailon | Hand-pump | 10.6 ± 1.0 |
| 14. | Changer | Water supply | 17.3 ± 1.3 |
| | | Hand-pump | 6.7 ± 0.8 |
| 15. | Bhota | Water supply | 2.4 ± 0.5 |
| 16. | Ramera | Well | 5.7 ± 0.7 |
| 17. | Jorre Amb | Hand-pump | 9.5 ± 1.0 |
| 18. | Neri | Hand-pump | 22.2 ± 1.5 |
| 19. | Ropa | Hand-pump | 10.0 ± 1.0 |
| *Mandi district* | | | |
| 20. | Ghatta | Hand-pump | 15.7 ± 1.3 |
| 21. | Patku | Hand-pump | 5.6 ± 0.7 |
| 22. | Ghuma | Natural spring | 6.4 ± 0.8 |
| 23. | Ulra | Natural spring | 5.6 ± 0.7 |
| 24. | Malog | Hand-pump | 26.6 ± 1.6 |
| 25. | Mandi | Hand-pump | 13.4 ± 1.2 |
| 26. | Mile Stone (Mandi 7 km) | Natural spring | 2.1 ± 0.5 |
| 27. | Jagar | Hand-pump | 11.0 ± 1.0 |
| 28. | Jagar 1 | Natural spring | 3.7 ± 0.6 |
| *Kullu district* | | | |
| 29. | Ghiri | Hand-pump | 48.0 ± 2.2 |
| 30. | Jari | *Thermal Spring* | *68.1 ± 2.6* |
| 31. | Mohal | Hand-pump | 6.8 ± 0.8 |
| 32. | Kasol | *Thermal Spring* | *K1 – 499.4 ± 7.1*<br>*K2 – 487.1 ± 7.0*<br>*K3 – 653.5 ± 8.1*<br>*K4 – 222.0 ± 4.7* |
| 33. | Bhuntar | Hand-pump | 38.0 ± 1.9 |
| 34. | Aut | Hand-pump | 12.5 ± 1.1 |
| 35. | Raison | Hand-pump | 10.2 ± 1.0 |
| 36. | Bihal | Hand-pump | 9.2 ± 1.0 |
| 37. | Kalath | Natural spring | 63.9 ± 2.5 |
| 38. | Vashishat | *Thermal spring* | *80.8 ± 2.8* |

*Statistical counting error – 1σ.
*Italics* indicates the radon concentration observed in thermal springs.

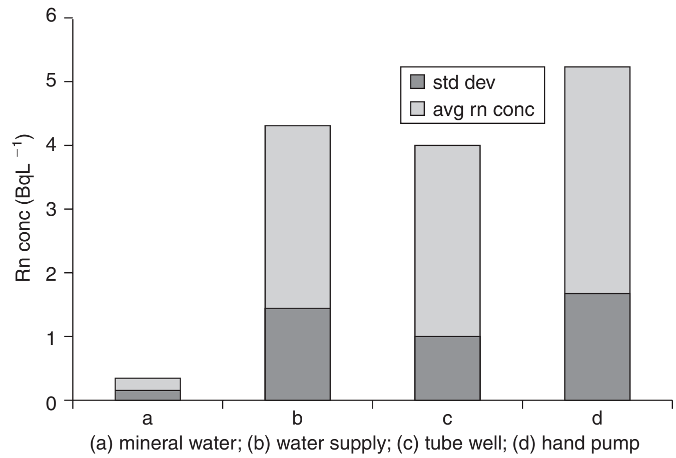


**Fig. 1.** Variation in the average radon concentration from different sources in Punjab.

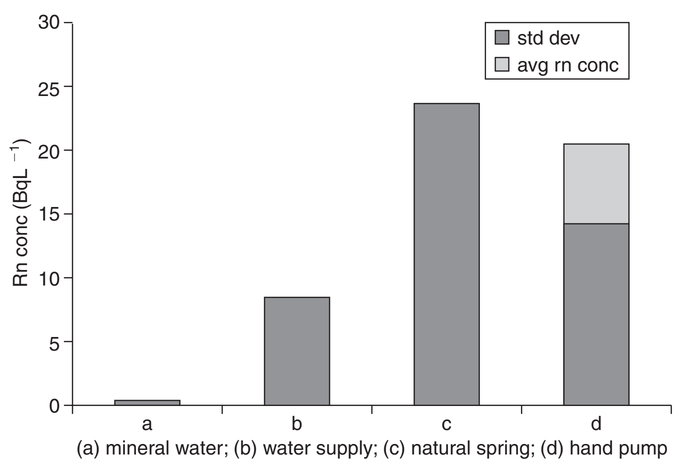


**Fig. 2.** Variation in the average radon concentration from different sources in Himachal Pradesh.

states, have been carried out during different time periods because of the wide range of distances and areas to be covered in these states. Secondly, although the indoor radon levels are strongly affected by the meteorological parameters and thus have strong seasonal variations, the groundwater radon does not seem to be much affected by the seasonal variation and so cannot be contributing much to the indoor radon levels in dwellings. The errors shown in the results are 1σ statistical counting errors, based on the number of counts recorded for the individual sample. The radon data has also been plotted in the form of a histogram (Figures 1–2) to study the variation of radon concentration with the source of drinking water in both the states.

## Discussion

In both the states, the radon concentration has been found to be a maximum in the case of groundwater drawn by hand-pumps, this may be because the loss of gas is at a minimum in water transported from the aquifer while the loss of gas is a maximum in water supplied after storage in a tank and circulation through the pipes as shown by the minimum radon concentrations in the water supply samples. Due to agitation and turbulence of tube-well drawn water, the radon gas dissipates at a faster rate into the air, hence lowering the radon concentration in case of tube-wells. Municipal water supplies also use the deep tube-well drawn water for storage and supply through the pipes. The loss of radon gas is compounded by storage and circulation over long distances. It has also been observed that thermal springs in the Kullu district of Himachal Pradesh recorded the highest values of radon concentration, while in Punjab the hand-pump shows relative high values as compared to other sources in this state. Actually the Kullu district of Himachal Pradesh is well known for its hot springs, especially at Kasol, Manikaran and Vashisth. The rock types found in the district are phyllite, slate, quartzite limestone, schists and granites and have been classified on the basis of their physical characters and mode and period of formation. Tourmaline granite, one of the type, is inferred to occur as intrusive and is the probable source of high radioactivity in areas where these rocks occur and many hot springs are seen around. This may be the reason for high concentrations of radon levels observed in the thermal springs of this district (represented in italics in Table 2). Even a natural spring at Kalath in this district shows a high radon concentration value of $63.9 \pm 2.5\,\mathrm{Bq \cdot L^{-1}}$ as compared to other natural springs.

The radon concentration measured in different mineral water samples supplied by different manufacturers has been found to have the minimum values (Table 3). The reason for negligible radon concentration in mineral water samples may be due to cascade distillation for removal of aerosol particles and other contaminants which adsorb radon and its progeny. This has been confirmed by comparison of radon concentration measured in double distilled water samples in our laboratory with that of mineral waters.

Overall the radon concentration values in groundwater of Himachal Pradesh, which is part of Siwalik Himalaya have been found to be higher than the Punjab state and these observed values have been found to be comparatively higher in groundwater than in surface water. Even the radon concentration in hand-pump drawn water samples has been found to be rising as we move from the Punjab alluvium to the Himachal Pradesh areas. The occurrence of radon in groundwater can reasonably be related to the uranium content of the bedrock and it can easily enter into the interacting groundwater by the effect of lithostatic pressure [11]. The histograms show that radon concentration is maximum in the case of groundwater drawn by hand-pumps and as we move from the Punjab alluvium towards Siwalik Himalaya in Himachal Pradesh, the average radon concentration increases (Figure 3). It is well established that Himalayan rivers and streams which charge the underground water table in Punjab contains anomalous values of uranium and radon concentrations some several times the average global value [12,13]. The observed standard deviation in the case of water supply and natural spring samples from Himachal Pradesh is high because fewer samples were collected from these sources. Although the radon concentration levels have been found to be higher in the groundwater of Himachal Pradesh than Punjab they are

**Table 3.** Radon concentration and pH of different mineral waters

| Source no. | Source | Radon conc. ($\mathrm{Bq \cdot L^{-1}}$) | pH |
|---|---|---|---|
| 1. | Mineral water (Aquafina) | $0.5 \pm 0.2$* | 7.4 |
| 2. | Mineral water (Bailley) | $0.7 \pm 0.3$ | 7.9 |
| 3. | Mineral water (Bagpiper) | $0.2 \pm 0.1$ | 7.7 |
| 4. | Mineral water (Bisleri) | $0.1 \pm 0.1$ | 7.4 |
| 5. | Mineral water (Rail-Neer) | $0.4 \pm 0.2$ | 7.2 |

*Statistical counting error – 1σ.

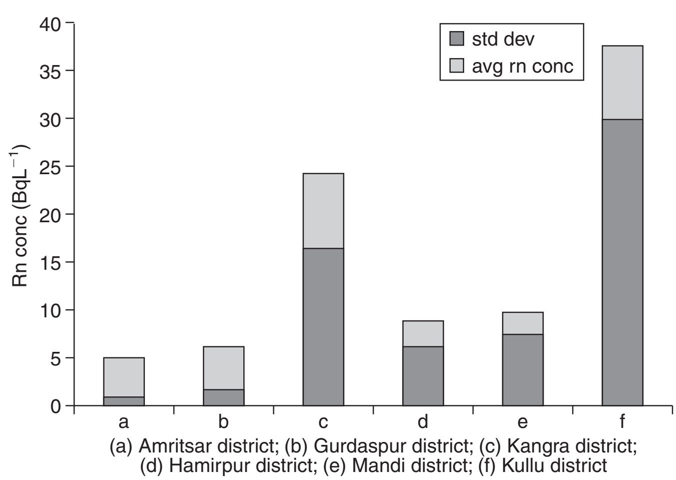


**Fig. 3.** Variation in the average radon concentration in groundwater from Punjab to Himachal Pradesh.

mostly within the internationally recommended [14] safe values of 4 to 400 Bq·L$^{-1}$ for groundwater used for human consumption and did not exceed that of the European Commission recommendation of 1,000 Bq·L$^{-1}$ [15]. Thus the observed values of radon concentration groundwaters of different districts of Punjab and Himachal Pradesh states are safe for drinking purposes. Even the higher groundwater radon levels will not contribute much to the indoor radon levels, because water is pumped from outside the dwellings, while direct consumption of drinking water with elevated radon levels particularly in the thermal springs which have the highest radon concentrations, may pose a health hazard to the people living in those areas.

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