Measurement of ^{222}Rn Concentration in Drinking Water in Northern Rajasthan, India

Vikas Duggal[a,*], Asha Rani[b], Rohit Mehra[c]

[a]*Department of Applied Sciences, Punjab Technical University, Jalandhar-144601, India*
[b]*Department of Applied Sciences, Ferozpur college of Engineering and Technology, Ferozshah, Ferozpur-142052, India*
[c]*Department of Physics, Dr. B. R. Ambedkar National Institute of Technology, Jalandhar-144001, India*
[*]*E-mail: vikasduggal86@yahoo.in*

Abstract

Radon activity concentrations were measured in drinking water samples collected from areas of Sri Ganganagar district of Rajasthan, India. The measurements were performed by RAD7 an electronic radon monitor manufactured by DURRIDGE COMPANNY, USA. The radon concentration in these samples is found to vary from (1.2 ± 0.5) to (4.1 ± 0.4) Bq l^{-1} with a mean value of (3.0 ± 0.8) Bq l^{-1}. The recorded values of radon concentration are within the safe limit of 11 Bq/l recommended by the US Environmental Protection Agency (USEPA). The annual effective dose in stomach and lungs per person is also evaluated in this research. The estimated total annual effective dose varies from 3.22 to 10.99 µSv y^{-1}. The total annual effective dose from all locations of the studied area is found to be within the safe limit (0.1 mSv y^{-1}) recommended by WHO and EU Council.

Keywords: *Annual effective dose; Drinking water; Radon; RAD7; Lungs; Stomach*

1. Introduction

Radon (^{222}Rn) is a naturally occurring radioactive noble gas with a half-life of 3.82 days, and it is a member of the ^{238}U decay series [1, 2]. Radon and its short-lived decay products such as ^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po at indoor places are recognized as the main source of public exposure by natural radioactivity, contributing to nearly 50% of the global mean effective dose to the public [3]. The exposure of population to high concentrations of radon and its daughters for a long period lead to pathological effects like the respiratory functional changes and the occurrence of lung cancer [4]. However, a very high level of radon in drinking water can also lead to a significant risk of stomach and gastrointestinal cancer [5]. When radon gas is inhaled, the highly-ionizing alpha particles emitted by deposited short-lived decay products of radon Polonium-218 and polonium-214 can interact with the biological tissue in the lungs leading to DNA damage that is considered as an important step in the carcinogenesis process. Since radon is a health hazard and a risk factor for some types of cancers including lung cancer [6], many studies have been conducted worldwide to determine its concentration in different environmental media in order to reduce its adverse effects on the human health [7-10]. Radon in household water supplies does pose a direct health risk in addition to its ability to enhance indoor radon [11, 12]. Radon was measured in water in many parts of the world, mostly for assessing the risk due to consumption of drinking water. High radon concentration has been reported in river waters of Garhwal and Siwalik Himalayas [13] and underground water of the Doon valley [14].

High radium concentration in soil and uranium content in groundwater samples were reported in northern region of Rajasthan State by our group [15, 16]. So, it was reasonable to design a study in order to investigate the radon levels in the groundwater. Our group earlier reports the radon concentration in groundwater in the small region of Sri Ganganagar district of Rajasthan [10]. Now the purpose of this study is to detail investigate the radon levels of groundwater being used for drinking and to determine the health hazards, if any, to the population groups belonging to the Sri Ganganagar district of Rajasthan state, India.

2. Geology of Sri Ganganagar

Rajasthan is located in northwest of India. The Sri Ganganagar district is situated in the northern most region of the state and forms a part of Indo-Gangatic plain. It is located between 28° 42' and 30° 11' North latitudes and between 72° 38' and 74° 17' East longitudes (Figure 1). It has a geographical area of 10978 Sq. Km. The population of Sri Ganganagar district is ~ 20 lakh. Residents of these areas are poor, mostly illiterate farmers, who use the groundwater for irrigation and for domestic consumption without prior treatment. It is bounded on the south by Bikaner district and on the east by Hanumangarh district and on the north by Faridkot & Ferozpur districts of Punjab and on west by Bahawalpur district of Pakistan. The climate of the district is marked by the large variation of temperature, extreme dryness and scanty rainfall. The area is covered by windblown isolated sand and alluvium except few patches of recent calcareous and sandy sediments associated with gypsite. The oldest rocks of the area belong to Aravalli Super Groups which includes phyllite, shale and quartz vein. These are overlaid by the rocks of the upper Vindhyan which are entirely made up of bright to pale red, fine and medium grained compact sand stone and siltstone.

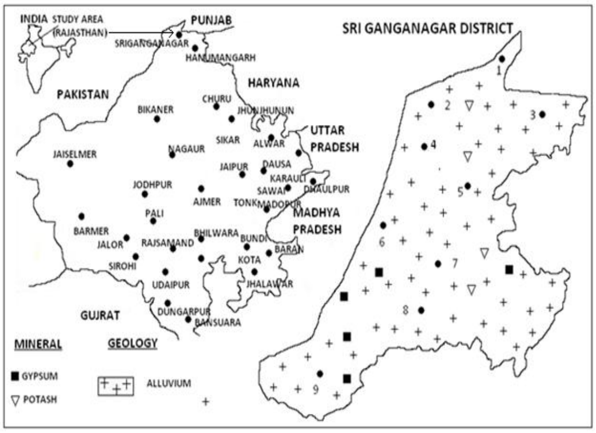

Figure 1. Shows the geographic location of the state of Rajasthan in India, as well as the location of the sampling sites in Sri Ganganagar district, Rajasthan.

The soils are mainly developed from the alluvium of variable texture and at places the alluvium is buried under the wind worked sand. These alluvial soils are moderately coarse textured, deep to very deep, underlained by weak concretionary zone and have been classified as Torrifluvents. The only major mineral of the district is gypsite.

3. Experimental Technique

A total of 36 water samples from hand pumps were collected and analyzed for radon concentration. Nine villages/towns were selected from the district in such a manner that the whole district has been covered. Four water samples were taken from each village and analyzed for radon concentration. Groundwater is used by the residents for domestic consumption without prior treatment. The RAD7 radon detector manufactured by DURRIDGE COMPANY Inc. has been used for radon concentration measurement in the water samples. The equipment is portable and battery operated, and the measurement is fast. Figure 2 shows the schematic diagram of RAD7 H_2O assembly. The water samples were taken in 250-ml vials designed for the RAD7 device and provided by the manufacturer. Water samples from hand pumps were measured for radon during the month of September-October 2012 and the weather conditions during the sampling period were fairly stable. The hand pumps from where the sample collection was done were in proper working condition. The system was pumped for 5 to 10 min before the sample was taken. Water sampling is complicated for the fact that the gas easily escapes from water, and therefore has to be done without any aeration, which might lead to outgassing. So the water samples should be collected in such a way that there should be no bubbling. In the present research, as a sample was collected, it was analyzed immediately on the entire sampling site. The time difference between taking the sample and analyzing it was few minutes, so no decay of radon in the water occurred. For accurate readings, the RAD7 has been dried out thoroughly to reduce the relative humidity below 10% before making each measurement.

The RAD7 H_2O is an accessory to RAD7 that enables measurement of radon in water over a concentration range from < 0.37 Bq l^{-1} to > 0.15×10^5 Bq l^{-1}. The operation of this instrument is based on the following principle: (i) radon is expelled from water sample by using a bubbling kit, (ii) expelled radon enters a hemisphere chamber by air circulation, (iii) polonium decayed from radon is collected onto a silicon solid state detector by an electric field, (iv) radon concentration is estimated from the count rate of polonium. RAD H_2O gives results after a 30 min analysis with a sensitivity that matches or exceeds that of liquid scintillation methods. The RAD H_2O method employs a closed loop aeration scheme whereby the air volume and water volume are constant and independent of the flow rate. The air recirculates through the water and continuously extracts the radon until a state of equilibrium develops. The RAD H_2O system reaches this state of equilibrium within about 5 min, after which no more radon can be extracted from the water.

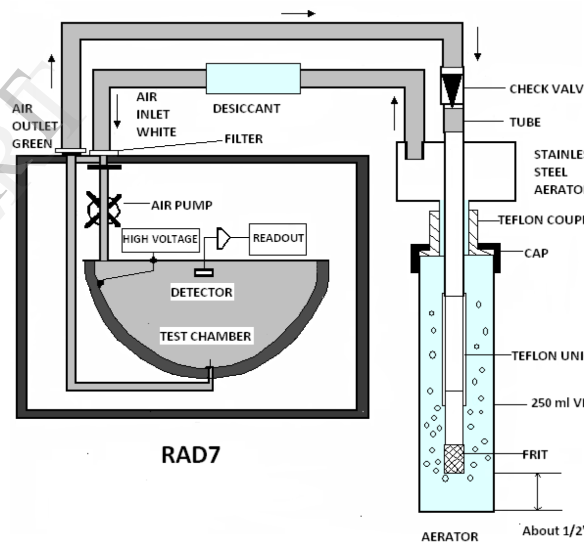

Figure 2. Shows the schematic diagram of RAD7 H_2O assembly.

The extraction efficiency or percentage of radon removed from the water to the air loop is very high about 94% for a 250 ml sample. The exact value of the extraction efficiency depends somewhat on ambient temperature, but it is almost always well above 90%. The RAD7 detector converts alpha radiation directly to an electric signal. The RAD7 has the ability to tell the difference between the new radon daughters and the old radon daughters left from previous tests. As per EPA recommendations that all continuous radon monitors be calibrated at least every 6 months in a radon calibration chamber, the instrument was calibrated recently [17].

4. Evaluation of mean annual effective dose

Radon enters human body through ingestion and through inhalation as radon is released from water to indoor air. Therefore, radon in water is a source of radiation dose to stomach and lungs. The annual effective dose for ingestion and inhalation were calculated according to parameters introduced by United Nations Scientific Committee on the Effects of Atomic Radiation report [3].

For ingestion, the following parameters were used:

(i) The effective dose coefficient from ingestion equals 3.5 nSv Bq^{-1} ;
(ii) Annual intakes by infants, children and adults are estimated to be about 100, 75 and 50 liters, respectively;
(iii) The annual effective doses, due to ingestion corresponding to 1Bq l^{-1}, would equal 0.35μSv y^{-1} for infants, 0.26μSv y^{-1} for children and 0.18μSv y^{-1} for adults.

For inhalation, the following parameters were used:

(i) Ratio of radon in air to radon in tap water supply is in the range of 10^{-4} Bq m^{-3};
(ii) Average indoor occupancy time per person is about 7000 h y^{-1};
(iii) Equilibrium factor between radon and its progeny is equal to 0.4;
(iv) Dose conversion factor for radon exposure is 9 nSv $(Bq.h\ m^{-3})^{-1}$
(v) The annual effective dose due to inhalation corresponding to the concentration of 1 Bq l^{-1} in tap water is 2.5 μSv y^{-1}. The World Health Organization [18] and EU Council [19] recommended 0.1 mSv y^{-1} annual effective dose from drinking water to be the safe limit from these three radioisotopes: ^{222}Rn, ^{3}H, ^{40}K.

5. Results and discussion

The results of ^{222}Rn measurements in groundwater in the Sri Ganganagar district are presented in Table 1. The values in samples from Sri Ganganagar district range from 1.2 ± 0.5 to 4.1 ± 0.4 Bq l^{-1} with an average value of 3.0 ± 0.8 Bq l^{-1}. In Sri Ganganagar district the maximum values of radon concentration are found in groundwater drawn by the hand-pumps at Sri Vijainagar, where as the minimum values are found at Mirzawala. The health and environmental protection agencies have recommended a safe limit of radon in drinking water for human beings. The US Environment Protection Agency has proposed that the allowed maximum contamination level (MCL) for radon concentration in water is 11 Bq l^{-1} [20]. The United Nations Scientific Committee on the Effects of Atomic Radiation has suggested a value of radon concentration in water for human consumption between 4 and 40 Bq l^{-1} [21]. These levels are set to represent a concentration that does not result in any significant risk to health over a lifetime's drinking water. The recorded values of radon concentration in groundwater are within the safe limit recommended by USEPA [20] and UNSCEAR [21]. All measured ^{222}Rn activity concentrations in groundwater are below the European Commission recommendation reference level for radon in drinking water of 100 Bq l^{-1} [22]. The radon equilibrium concentrations in groundwater generally range between about 1 and 50 Bq l^{-1} but can be much higher as result of a high radium concentration in the aquifer matrix [23].

Table 1. Results of ^{222}Rn measurements in groundwater.

Sample Location	Mean ^{222}Rn Conc. (Bq l^{-1})	Annual effective dose (μSv y^{-1})		
		Stomach	Lung	Total
Hindumalkot	3.5±0.6	0.63	8.75	9.38
Mirzawala	1.2±0.5	0.22	3.00	3.22
Sadulshahar	3.0±0.8	0.54	7.50	8.04
Nizampura	2.4±0.5	0.43	6.00	6.43
Padampur	3.6±1.4	0.65	9.00	9.65
Lalgarh	3.3±0.9	0.59	8.25	8.84
Raisinghnagar	2.6±1.2	0.47	6.50	6.97
Sri Vijainagar	4.1±0.4	0.74	10.25	10.99
Anupgarh	3.7±0.4	0.67	9.25	9.92

The annual effective dose in stomach and lungs per person was also evaluated in this research. The values of the mean annual effective dose per person caused by different water samples in this study are reported in Table 1. The estimated total annual effective dose of adults ranged from 3.22 to 10.99 μSv y^{-1}. The World Health Organization [18] and EU Council [19] recommended a 0.1 mSv y^{-1} annual effective dose from drinking water to be the safe limit from these three radioisotopes: ^{222}Rn, ^{3}H and ^{40}K. So the total annual effective dose from all the locations of the studied area is found to be well within the safe limit.

6. Conclusions

In the paper the results of the ^{222}Rn measurements in 36 groundwater samples collected SriGanganagar district are presented. The measurements were performed by RAD7 radon detector manufactured by DURRIDGE COMPANY Inc. The observed values of radon concentration in groundwater of different areas of SriGanganagar district of Rajasthan state are within the international recommended limit and hence safe for drinking purposes. The total annual effective dose from all locations of the studied area is found to be within the safe limit (0.1 mSv y^{-1}) recommended by World Health Organization and EU Council. The results show no significant radiological risk due to radon ingestion for the inhabitants of the studied regions.

Acknowledgements

The authors are thankful to the residents of the study area for their cooperation during the field work and the Department of Physics, B.R.A.N.I.T., Jalandhar, for allowing us to use its instruments.

References

[1] K. Somlai, S. Tokonami, T. Ishikawa, P. Vancsura, M. Gaspar, V. Jobbagy, J. Somlai, and T. Kovacs, "^{222}Rn concentration of water in the Balaton Highland and in the southern part of Hungary, and the assessment of the resulting dose", Radiation Meas., 2007; 42:491-495.

[2] V. Duggal, A. Rani, and R. Mehra, "Measurement of indoor radon concentration and assessment of doses in different districts of Northern Rajasthan, India", Indoor and built Environ., 2013, pp. 1-9. DOI: 10.1177/1420326X13500801

[3] United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the general assembly with scientific annexes. Sources and Effects of Ionizing Radiation, Vol. 1, Annex B: Exposures from Natural Sources of Radiation, United Nation, New York, 2000.

[4] BEIR VI, Reports of the committee on the Biological effects of ionizing radiation, Health effects of exposure to radon. Natl. Res. Council. Natl. Acad Press, Washington, DC, 1999.

[5] G.M. Kendal, and T.J.Smith, "Dose to organs and tissues from radon and its decay products", Journal of Radiological Prot., 2002; 22:389-406.

[6] WHO handbook on indoor radon a public health Perspective. 1:4, 2009.

[7] A. Mustafa, J. Patel, and I. Rathore, "Preliminary report on radon concentration in drinking water and indoor air in Kenya", Environ Geochem Health, 2002; 24:387-396.

[8] W. D'Alessandro, and F. Vita, "Groundwater radon measurements in the Mt. Etna area, Italy", Journal of Environmental Radioact., 2003; 65:187-210.

[9] V. Duggal, R. Mehra, and A. Rani, "Determination of ^{222}Rn level in groundwater using a RAD7 detector in the Bathinda district of Punjab, India", Radiation Protection Dosim., 2013; 156(2):239-245.

[10] A. Rani, R. Mehra, and V. Duggal, "Radon monitoring in groundwater samples from some areas of Northern Rajasthan, India, Using a RAD7 detector", Radiation Protection Dosim., 2013; 153(4):496-501.

[11] F.T. Cross, N.H. Hartley, and W. Hoffmann, "Health effect and risk from ^{222}Rn in drinking water", Health Phys., 1985; 48:649-670.

[12] C.T. Hess, J. Michel, T.R. Horton, H.M. Prichard, and W.A. Coniglio, "The occurrence of radioactivity in public water supplies in the United States", Health Phys., 1985; 48:553-586.

[13] H.S. Virk, and M. Singh, "Uranium and radon anomalies in the river system of N-W Himalaya", Indian J Environ Prot., 1999; 19:750-752.

[14] V.M. Choubey, S.K. Bartarya, N.K. Saini, R.C. Ramola, "Impact of geohydrology and neotectonic activity on radon concentration in groundwater of intermontane Doon Valley, Outer Himalaya, India", Environ Geol., 2001; 40:257-266.

[15] V. Duggal, A. Rani, R. Mehra, and R.C. Ramola, "Assessment of natural radioactivity levels and associated dose rates in soil samples from Northern Rajasthan, India. Radiat. Prot. Dosim., 2013, pp. 1-6. Doi:10.1093/rpd/nct199

[16] A. Rani, R. Mehra, V. Duggal, and V. Balaram, "Analysis of uranium concentration in drinking water samples using ICPMS. Health Phys., 2013; 104:251-255.

[17] DURRIDGE Company, RAD7, RAD H_2O accessory owner's manual. [http:// www.durridge.com/documentation/ RADH$_2$OManual.pdf].

[18] World Health Organization, Third ed. Guidelines for Drinking water Quality, vol. 1. Geneva, 2004.

[19] European Commission, European drinking water directive 98/83/EC of 3rd November 1998 on the quality of water intended for human consumption. Official Journal L 330, 1998.

[20] United States Environmental Protection Agency, Federal Register 40 Parts 141 and 142 National Primary Drinking Water Regulations; Radionuclides: Proposed Rule. U.S. Government Printing Office, Washington, DC, 1991.

[21] United Nations Scientific Committee on the effects of Atomic Radiation, Sources and effects of Ionizing Radiation. UNSCEAR 2008 report to the general assembly with Scientific annexes, New York, United Nations, 2008.

[22] EUROPEAN COMMISSION, Commission recommendation of 20th December 2001 on the protection of the public against exposure to radon in drinking water. 2001, 2001/982/Euratom, L344/85, 2001.

[23] M. Schubert, L. Brueggemann, K. Knoeller, and M. Schirmer, "Using radon as an environment tracer for estimating groundwater flow velocities in single-well tests", Water Resources Res., 2001; 47:W03512. doi: 10.1029/2010WR009572