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Estimation of Inhalation and Ingestion Dose Due to Radon Concentration in Drinking Water Samples of Shankaraghatta Forest Environment, Karnataka, India

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Abstract

Objectives: To estimate inhalation and ingestion doses due to radon concentration in rural areas of Shankaraghatta forest environment, India. **Methods**: In this study, the risk due to radon concentration in underground drinking water samples of the Shankaraghatta region has been estimated using emanometry technique. The 44 drinking water samples were collected from different water sources in sample bottles (500 ml) and were carefully sealed to ensure there is no air gap and were analysed within 24 hours by radon bubbler technique using a Lucas cell. **Findings**: The radon (^{222}Rn) concentration in underground and surface water samples of the entire region varies from 1.10 $\pm$ 0.25 $Bq\,l^{-1}$ to 30.67 $\pm$ 5.10 $Bq\,l^{-1}$ with an average value of 13.10 $\pm$ 2.2 $Bq\,l^{-1}$, is higher than the USEPA proposed maximum contamination threshold of 11Bql^{-1}.The Annual Effective Dose Equivalent (AEDE) ranges from 3.86 $\mu Sv\,y^{-1}$ to 83.80 $\mu Sv\,y^{-1}$ with an average value of 36.35$\mu Sv\,y^{-1}$, which is slightly higher than the global average value. **Novelty**: The present work focuses on the public health of the study area where such estimation was not carried out. The estimated annual effective, inhalation and ingestion doses due to radon in underground drinking water samples are found to be substantially below the 100 μSvy^{-1}recommended by WHO and EC. Hence, public of the study area won't receive any serious health hazard due to radon in drinking water and the water is fit for drinking without any additional treatment.

Keywords: Radon Concentration; Underground and Surface water; Emanometry Technique

1 Introduction

The measurement of radon in the environment matrix is important all over the world due to the fact that inhalation of radon and its progeny contribute more than 55% of the total natural background radiation dose to the human being[1,2]. Testing its level of contamination, monitoring its concentration, assessment of dose due to inhalation and ingestion in underground drinking water is became a priority aspect for purpose of public health awareness but it is challenging to estimate the radiation doses that living things are exposed to as a result of radon and its progeny because of the complex interactions between radon's radioactive progeny, chemical forms, and its attachment to aerosols, as well as the intake, deposition, and retention of radon-related radioactivity in living things. Hence, addressing the existing problems all over the globe, several studies have been carried out by many researchers using both active and passive methods such as CR-39, RAD7, and Lucas Cell[3]. Regulated levels of this radon in drinking water have been set by numerous international organizations. 11 Bql^{-1} is the maximum contamination limit (MCL) for radon in drinking water[4].

In Malaysia Penang region Najeba F. Salih (2021) investigated the radon concentration in drinking water using both active and passive methods (CR-39 & RAD7) and their results show that there is a strong and significant correlation found in both active and passive techniques[5]. In their study, they estimated radon activity concentration in water samples by using both active and passive methods (CR-39). In the passive method to establish equilibrium between the radium and radon the sample is kept in a tube for about 60 days, which is a prolonged period of time (60 days) during this weighting period there is a possibility of samples getting destructed even at the time of etching process or there might be chances of getting back diffusion of radon even though the tube is airtight and care is taken. There is always a bit of risk involved in maintaining the samples for such a long period. Hence, the passive method turns out to be a time-consuming and inconvenient method.

While the active method was implemented by many researchers. Biljana Vuckovivc´et al. (2022) in the north of Kosovo region had investigated the radon in drinking water samples of north Kosovo using RAD7 and their results show that radon in drinking water was found to be 12.4 $\pm$ 2.0 Bq l^{-1} [6]. In their study, the author studied only two types of water samples and the geological formation predominantly consists of neogenic, sediments, and magmatic rocks.

Suresh et al. (2022) in Uttar Kannada, India investigated the radon concentration in different types of groundwater samples in the Uttar Kannada district using the active method (Emanometry-Lucas cell method) and their result shows that the radon concentration in groundwater samples is 26.23 $\pm$ 0.65 Bql^{-1} [7]. The study area predominantly consists of Lithological formations such as granites, metabasalt, and granitic gneiss. Hence Biljana Vuckovivc´et al and Suresh S et al. observed different results because radionuclide content varies with the type of rock system[8]. Therefore, the radon concentration in water samples purely depends upon the local geology and geography of the study area. The present study area consists of Migmatite rock, Granodiorites-Tonalitic gneiss, and Ultramafic Schist. Hence, one can expect variations in radon concentration.

In the present study measurement of activity concentration and annual effective dose of radon in groundwater was carried out using emanometry technique (Lucas cell methods) because Mostafa et al. (2022) used RAD7 for the measurement of radon in water and observed measurements with RAD7 affected by various factors including the sampling method, sample size, counting interval, temperature, relative humidity, and background[9]. This causes errors in the measurement of radon concentration. Hence, in the current study, we have used the Lucas cell method. The key component of the procedure is the washing of radon from a large sample of water (0.75l) to a small volume of air (0.6l), which results in a high radon concentration in the air and gives a significant increase in measurement sensitivity compared to RAD7. Moreover, this method is a convenient, economical, and efficient method, giving almost comparable results recommended by various international research organizations such as UNSCEAR, USEPA, ICRP, EC, and WHO.

In view of this importance and to reduce the possible adverse health effects on human beings. The present study involves the measurement of activity concentrations of radon in 44 water samples from 6 different water resources and the annual effective dose of radon in groundwater samples for different age groups were also estimated. The purpose of the present study focuses on the estimation of radon concentration in drinking water, inhalation, and ingestion dose to the public, to reduce possible health risks, to take preventive measures, and also to provide baseline data for further epidemiological studies in future research work.

2 Methodology

2.1 The Study Area

Shankaraghatta region, which is hilly and rich in natural history, is located between $75^0 39' 30''$ East longitude and $13^0 45' 30''$ North latitude. It is the jewel of the Western Ghats because of its lush hills and high elevation. This area is abundant in biodiversity and is home to numerous endemic species. The districts of Shivamogga and Chikkamagaluru in the state of Karnataka are included in the study region. The region is covered in deep forests, and has steep, hilly Malnad in the west, sparsely forested tablelands, and semi-malnad in the east. It also has several natural water sources, including the Bhadra River, a major supply of portable water, as well as hand pumps and bore wells. The study area is comprised of lithology which includes the rock formations made up of Migmatite rock, Granodiorites-Tonalitic gneiss, and Ultramafic Schist. These rock systems contain radionuclides[8]. The three main types of soil that can be found in the study region are clay, red sandy clay loam, and habitat masks. Due to this reason, one can expect a higher concentration of radon in this region and in the underground water. Moreover, the Shankaraghatta region in Badhravathi taluk has a population of around 13000 and this region is the hub for higher education, it includes 3500 students 600 teaching and non-teaching staff[8]. This reason the study area is chosen because of the importance of water and public health. Also, this study aims to estimate the inhalation and ingestion doses due to radon in groundwater and to monitor the quality of drinking water from underground and surface water resources. The investigations and collection of samples were carried out during the period of November 2022.

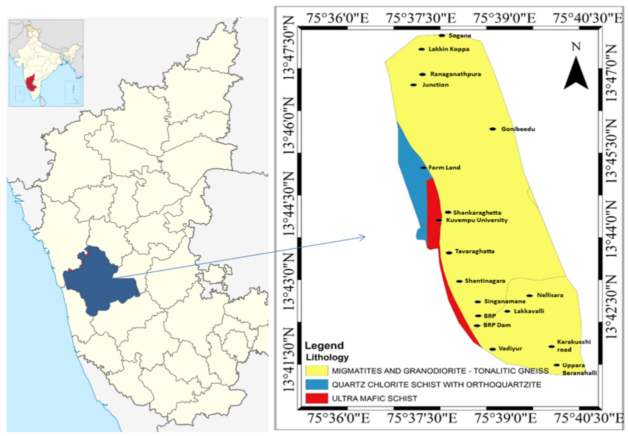

Fig 1. Geological Map of measurement of radon concentration in drinking water samples in the environment of Shankaraghatta

Measurements are carried out using the portable Lucas cell with a programmable alpha counting system and a radon bubbler chamber and it is discussed below.

Drinking water samples were collected from 44 distinct places in the Badhravathi taluk of Shivamogga district's Shankaraghatta and adjacent villages. The bore well, open well, hand pump, and public tap water samples are collected. Four samples were obtained from each site to determine the repeatability of radon concentrations. Water samples were collected (500ml) in an airtight plastic bottle. The plastic bottles were carefully packed to ensure that there was no air gap. Within 24 hours, all of the samples collected were analyzed. The emanometry technique was used to determine the concentration of ^{222}Rn in drinking water Figure 2 [1,9]. Once when, all the water samples using the aforementioned conventional approach, samples were transported to the laboratory, PSI-RBS-1model is specially designed for Radon Bubbler, which is made up of corning glass with a leak-free sintered disc, airtight joints and PTFE bore-glass stop cocks[7,10]. Leak-free coupling for gassing and degassing of samples as well as radon sampling to Lucas cells are provided. A radon bubbler is often used to measure the radon concentration of liquid samples. Figure 3 shows the experimental setup of the Emanometry technique.

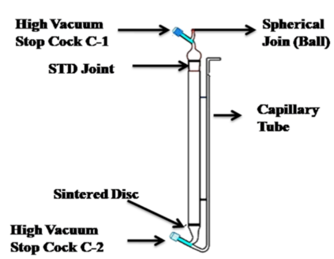

Fig 2. An illustration of a Radon-bubbler

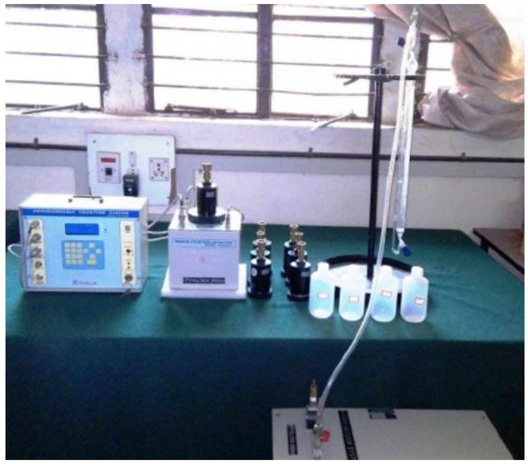

Fig 3. Experimental setup of Emanometry technique

In the bubbler, approximately 70 ml of the water is filled, and the dissolved radon in the water is transported to a Lucas cell that had been pre-evacuated and counted for background counts. Radon is allowed to reach equilibrium with its daughter products for about 3 hours in the Lucas cell.

Lucas Cell: It consists of cylindrical chamber, which is coated internally with ZnS (Ag), has a maximum wavelength of 4500Å with scintillating property. A photomultiplier tube detects the light signal created when an alpha particle collides with the ZnS phosphor and converts it into an electrical count. It's having a radius of 2.2 cm and an interior height of 7 cm. To sample or evacuate radon, one end of it is attached to a Swagelok quick connecter, while the opposite window is sealed with transparent glass to couple with a counting device.

Later it is connected to the PMT (photomultiplier) tube and an alpha counting assembly and counted for 17 minutes. The formula used to calculate the radon concentration in the groundwater sample is given in equation (1) below[10,11].

$$222_{Rn}\left(Bql^{-1}\right) = \frac{6.97\times 10^{-2}\times C_B}{E\times V\times\left(1-e^{-\lambda\Theta_t}\right)e^{-\lambda\Theta_t}} \tag{1}$$

Where: $C_B$is the total Counts above background, V is the volume of water (in L), E represents the Efficiency of the Scintillation/Lucas cell (74%), λ represents decay constant for radon $\left(2.098\times 10-6\ \mathrm{s}^{-1}\right)$, θ_t, is the delay time after sampling.

2.2 Estimation of Inhalation dose and Ingestion dose due to ^{222}Rn in drinking water

The annual effective doses of radon in water for inhalation and ingestion were determined using the formula UNSCEAR (2000) criterion, as given by

$$E_{in}\left(\mu Svy^{-1}\right) = R_{CW}\times R_{aw}\times E_q\times A_{\mathrm{int}}\times DCF \tag{2}$$

Where: E_{in} represents the effective dose for inhalation,R_{CW}represents the radon concentration in water $(Bql^{-1}orkBqm^{-3})$, R_{aw}represents the radon in air to water ratio(10^{-4}),E_q represents the equilibrium factor of radon and its progenies (0.4), A_{int} represents the average indoor occupancy time per individual (7000 ha^{-1}), DCF represents the conversion factor for radon exposure dose [9n Sv $(Bqhm^{-3})^{-1}$].

The following formula is used to calculate the ingestion dose:

$$D_{ing} = R_{CW}\times W_C\times E_D -----3 \tag{3}$$

Where: $D_{ing}\rightarrow$ the effect dose for ingestion,R_{CW} represents the radon concentration levels in drinking water (Bql^{-1}), W_C represents estimated water consumptions (60 la^{-1}), $E_D$represents the effective ingestion dose (3.5 nSvBq^{-1}).

$$TD_{ing}\left(\mu Svy^{-1}\right) = R_{CW}\times DWC\times C_F\times E_T \tag{4}$$

TD_{ing}Represents total effective dose, R_{CW} represents the radon concentration levels in drinking water (Bql^{-1}), DWC represents daily water consumption E_T exposure time. Table 2 provides the DWC for the public of various age groups, including infants, children, males, females, pregnant women, and lactating women, for use in determining doses from drinking water consumption[10,11].

$$\text{Effective Dose } \left(\mu Svy^{-1}\right) = T_{WF} \times D_{In}.D_{Ing} \tag{5}$$

Where: T_{WF} represents the tissue weighting factor (Lungs, Stomach;T_{WF}=0.12)

3 Result and Discussion

3.1 Radon concentration in the drinking water

Table 1 shows the average radon concentration of 44 drinking water samples collected from different locations of the Shankaraghatta. The average values of radon concentration in drinking water samples vary from 1.41± 0.25$Bq\ l^{-1}$to 30.67±5.10$Bq\ l^{-1}$, with an average value of 13.10 ± 2.2 $Bq\ l^{-1}$. The drinking water samples collected from groundwater sources such as bore wells and hand pumps have shown higher radon concentrations among all the samples that are analyzed. This may be due to its increased depth, which allows water to interact with a thicker aquifer, resulting in higher levels of radon in hand pumps and bore wells[7,12].

The higher concentration of radon in the drinking water was found at locations such as the Farmland, Teacher's Quarters, Ladies hostel Lakkavalli Five Light Circle, Karkucchi road, Sogane and Ranganathpura. This may be due to the presence of a granodiorite gneiss rock system (Figure 1). This region consists of the geology of quartz chlorite Schist with orthoquartzite which consists of mineral composition, the depth of groundwater sources also plays a predominant role for higher concentration[7,10]. A granitoid is a 90 percent coarse-grained material. It has a quartz content of 20–60% and a plagioclase content of 65–90%. The roughly analogous intrusive rock to rhyodacite is composed of coarse-grained plutonic rocks that contain quartz, plagioclase (oligoclase or andesine), and minerals like subordinate potassium feldspar. Mafic components may also include biotite, hornblende, or, less frequently, pyroxene.[13].The lower concentration is observed at B.R.P Gramapachayath, Singanamane village bore wells, this may be due to the less depth of bore well. Migmatite and granodiorite dominate the research region. These rocks contain quartz, clays, orthoclays, biotite, amphibol, hornblend, and silicate as their main minerals[8]. The mineral makeup of feldspar and other minerals affects the radionuclides[14]. The lower concentration was found for surface water at locations such as Gonibeedu, Channel, BRP Dam water, and Shanthinagara pond. This may be due to diffusion losses to the atmosphere[15].

The maximum radon contamination limit (MRCL) in groundwater has been proposed by the US Environmental Protection Agency to be 11.1 Bql^{-1} [16]. It is clear from this that among all the samples 75 percent of bore wells and hand pumps contain radon concentration values of more than 11.1 $Bq\ l^{-1}$. The United Nations Scientific Committee on the Effects of Atomic Radiation recommends a radon concentration in drinking water vary from 4 to 40 $Bq\ l^{-1}$for human consumption[17]. It is clear from the data (Table 1) that all the water samples of the study area contained radon values of less than 40$Bq\ l^{-1}$. The average measured radon concentration in drinking water samples of the Shankaraghatta region was found to be 13.10 $Bq\ l^{-1}$, which is higher compared to the US Environmental Protection Agency[16] for public protection against radon exposure in drinking water supplies, and lower compared to the WHO's recommended radon in drinking water limit, which advises a 100 $Bq\ l^{-1}$ action level for public water supplies[18]. When these data are compared, it is clear that the major source of health risk in the case of water is radon inhalation. Our average annual effective doses of 2.80 μSvy^{-1} and 33.57μSvy^{-1} from radon in water owing to ingestion and inhalation respectively, which are marginally higher than average annual effective doses of 2 and 25μSvy^{-1} due to ingestion and inhalation[19]. The findings show that the total annual ingestion dose exposure from the water samples was significantly below the WHO standard threshold of 100μSvy^{-1}, indicating that the ^{222}Rn dosages ingested by water in the study locations does not pose any health risks.

When compared to radon gas inhalation, the radiation dosage from radon in drinking water is modest. Both of these radon sources, however, should be treated with caution and should take appropriate precautions to reduce radon exposure through drinking water. As a result, according to state legislation, any new supply of drinking water must undergo radon and another radioactive testing before being utilized for public use[20].

Table 1. The average ^{222}Rn concentration in 44 drinking water samples of different locations in Shankaraghatta region

Sl. No	**Name of the Locations**	**Type of water Source**	**^{222}Rn Conn. ($Bq\ l^{-1}$)**	**Annual Effective Dose Equivalent Total Dose(μSvy^{-1})**				
				Inhalation (a)	**Lung**	**Ingestion (b)**	**Stomach**	**Total (a+b)**

Continued on next page

Table 1 continued

1	Shankaraghatta	OW	03.24 ± 0.50	08.05	1.00	0.67	0.10	08.72
2	Kuvempu University-1	BW	17.94 ± 0.95	45.07	5.41	3.76	0.50	48.82
3	Kuvempu University-2	TW	02.41 ± 1.29	06.08	0.73	0.51	0.10	06.59
4	Teachers Quarters	BW	28.21 ± 2.00	71.00	8.50	5.90	0.70	77.50
5	Ladies hostel	BW	25.10 ± 0.50	63.20	7.60	5.30	0.59	68.50
6	Kuvempu Nagara	BW	09.37 ± 1.29	23.78	2.85	1.98	0.24	25.76
7	Tipperudrappa layout	BW	12.22 ± 2.57	30.79	3.69	2.57	0.31	33.35
8	Kudremukh Layout	BW	14.08 ± 0.95	35.60	4.27	2.97	0.36	38.57
9	Tavaraghatta-1	BW	10.06 ± 3.90	25.41	3.05	2.12	0.25	27.52
10	Tavaraghatta-2	HP	11.29 ± 2.89	28.41	3.41	2.37	0.30	30.78
11	Malenahalli-1	BW	10.24 ± 4.10	25.79	3.10	2.15	0.30	27.94
12	Malenahalli-2	HP	12.44 ± 2.76	31.25	3.75	2.60	0.31	33.85
13	Sompura Road-1	HP	14.67 ± 1.29	37.05	4.45	3.09	0.40	40.13
14	Sompura Road-2	BW	16.86 ± 0.75	42.51	5.10	3.54	0.43	46.05
15	Gonibeedu-1	HP	11.67 ± 3.30	29.41	3.53	2.45	0.30	31.86
16	Gonibeedu-2	BW	13.29 ± 3.50	33.63	4.04	2.80	0.30	36.43
17	Gonibeedu-3	CW	1.41 ± 0.25	03.57	0.43	0.30	0.04	03.86
18	Tammadi Halli	HP	12.29 ± 2.70	31.10	3.73	2.59	0.31	33.69
19	Farm Land	BW	30.67 ± 3.30	77.30	9.30	6.40	0.80	83.80
20	Junction-1	BW	15.24 ± 5.10	38.19	4.58	3.18	0.38	41.37
21	Junction-2	HP	16.45 ± 0.95	41.50	4.98	3.46	0.41	44.96
22	Umble bailu road	HP	12.01 ± 2.20	30.27	3.63	2.59	0.30	32.80
23	Ranganathpura	HP	23.08 ± 2.10	58.32	7.00	4.86	0.58	63.18
24	Lakkin Koppa -1	BW	19.78 ± 4.25	49.92	5.99	4.16	0.50	54.08
25	Lakkin Koppa-2	TW	1.80 ± 0.45	04.60	0.55	0.38	0.03	04.98
26	Kallihalu	BW	9.50 ± 1.50	23.93	2.87	1.99	0.24	25.93
27	Sogane	BW	23.22 ± 3.25	58.57	7.03	4.88	0.59	63.45
28	Shanthinagara-1	HP	11.50 ± 3.10	28.87	3.46	2.41	0.29	31.28
29	Shanthinagara-2	PW	1.57 ± 0.25	04.06	0.50	0.33	0.04	04.31
30	BRP	HP	10.18 ± 2.80	25.61	3.07	2.13	0.26	27.75
31	B.R.P.Grama panchayath	BW	8.06 ± 1.57	20.54	2.46	1.71	0.21	22.25
32	Singanamane-1	BW	8.89 ± 2.45	22.42	2.69	1.87	0.22	24.29
33	Singanamane-2	HP	13.29 ± 3.50	33.52	4.02	2.79	0.34	36.31
34	Bhadra Dam -1	RW	1.57 ± 0.25	04.06	0.49	0.34	0.04	04.40
35	Bhadra Dam -2	BKW	1.73 ± 0.57	04.24	0.51	0.35	0.04	04.60
36	Garage camp	HP	10.19 ± 2.19	25.73	3.09	2.14	0.26	27.88
37	Vadiyuru	HP	10.56 ± 1.81	26.60	3.19	2.22	0.27	28.81
38	Lakkavalli Five Light Circle	HP	28.37 ± 3.38	71.61	8.59	5.97	0.72	77.58
39	Lakkavalli Canara bank	HP	14.11 ± 4.30	35.48	4.26	2.96	0.35	38.44

Continued on next page

Table 1 continued

40	Uppara beerana Halli	HP	15.50 ± 2.85	39.01	4.68	3.25	0.39	42.26
41	Nellisara-1	BW	18.61 ± 3.75	46.86	5.62	3.91	0.47	50.77
42	Nellisara-2	HP	16.24 ± 3.25	40.73	4.89	3.39	0.41	44.12
43	Karkucchi Road	BW	23.29 ± 2.50	58.59	7.03	4.88	0.59	63.47
44	Someshwara temple	OW	4.37 ± 1.57	11.18	1.34	0.93	0.11	12.111
	MAX		30.67 ± 5.10	77.30	9.30	6.40	0.80	83.80
	MIN		1.41 ± 0.25	3.57	0.43	0.30	0.03	3.86
	AVG		13.10 ± 2.20	33.54	4.03	2.80	0.34	36.35
	GM		10.20 ± 1.70	26.27	3.16	2.19	0.27	28.45
	SD		7.50 ± 1.30	18.88	2.26	1.57	0.19	20.49

(Note: OW=Open Well; BW=Bore Well; HP = Hand Pump; TW= Tank Water; PW=Pond Water; RW=River Water= Channel water; BKW= Back Water)

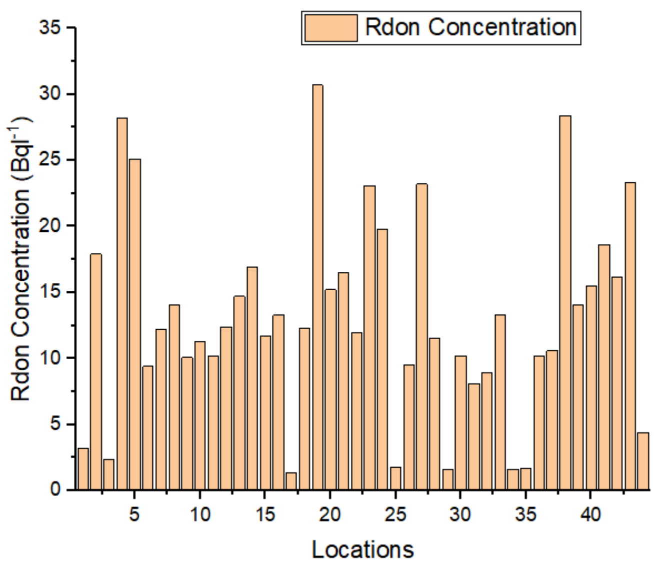

Fig 4. Radon Concentration v/s different locations

Figure 4 shows the variation of wide variation of ^{222}Rn concentration in 44 different locations of the Shankaraghatta forest environment. This might be because radionuclides like ^{238}U and ^{226}Ra, which are present in soil and rocks in various concentrations are present [7]. As a result, radon can easily pass through porous rocks that are beneath saturated underground aquifers. The radon that is present in the soil and rocks may readily dissolve into the water when it comes from these pores and be carried there with it [7]. Various factors influence the radon concentration in water such as geology, the type of aquifer found in those particular locations [12]. The higher radon concentration is indeed mostly due to the deeper wells and hand pumps. The hand pumps and deeper bore wells enable more water to interact with the aquifer's substantial thickness [7,10].

Figure 5 shows the variation of radon concentration in different sources of drinking water samples, the graph clearly shows that the radon concentration from groundwater samples such as bore well, hand pumps, and open well has shown higher concentrations than the surface water samples. This may be due to the fact that the depth of the bore well and hand pump, greater the depth means it allows water to interact with the aquifers significantly, and also this may be due to the radionuclides present in the soil and rock system [7,10,12,18]. But the radon concentration in the tap water (TP), backwater (BKW), and pond (P) have shown lower radon concentration this may be due to dissolved radon being disrobed and later released along the path water body source and the sample collection point. Also, surface water shows lower radon concentration [12], because of variations in atmospheric temperature, moreover surface water is well exposed to the atmosphere therefore dissolved radon gets easily discharged. Hence, lower concentrations can be found [10].

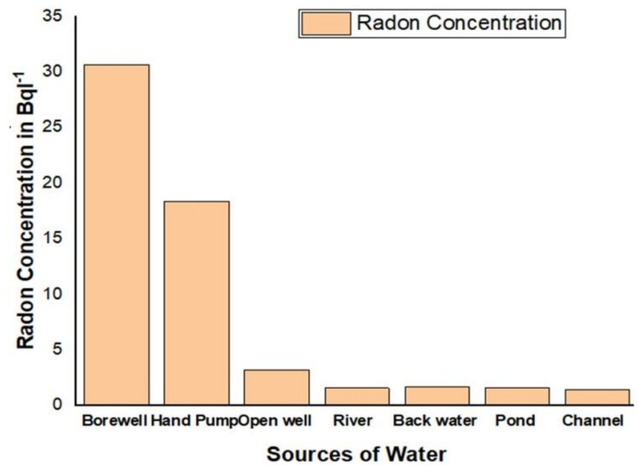

Fig 5. Variation of radon concentration in different sources of drinking water sample

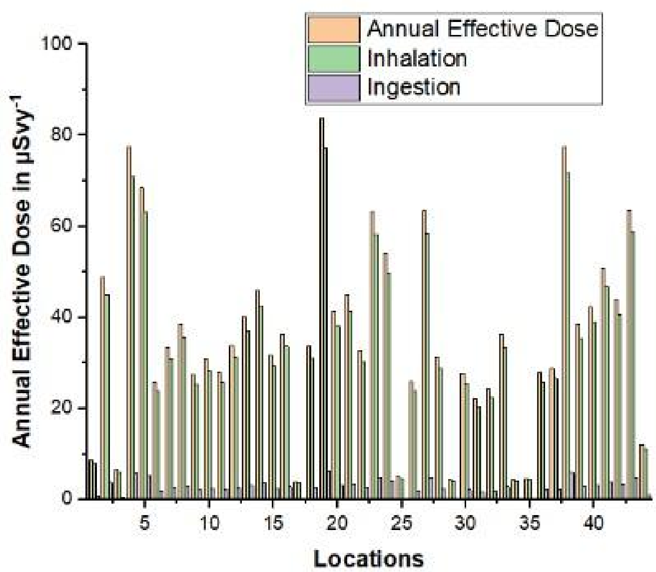

Fig 6. Variation of Inhalation, Ingestion & Annual effective dose equivalent with different Alocations of Shankaraghatta

3.2 Annual effective dose equivalent

Figure 6 shows the variation of the total dose, inhalation, and ingestion dose with locations. The inhalation dose of the study area varies from 3.57 $\mu Svy^{-1}$to 77.30 μSvy^{-1} with an average of 33.54 μSvy^{-1}. The ingestion dose received varies from 0.30 μSvy^{-1} to 6.40 μSvy^{-1} with an average of 2.80μSvy^{-1}. The quantity of radon reaching the lung varies from 0.43 $\mu Svy^{-1}$to 9.30 $\mu Svy^{-1}$with an average of 4.03 μSvy^{-1}. The quantity of radon from these sources reaching the stomach varies from 0.03 to 0.80 with an average of 0.34 and the total annual effective dose rate due to both inhalation and ingestion varies from 3.86 to 83.80 μSvy^{-1} with a mean of 36.35 μSvy^{-1}, which is less than the100 $\mu Svy^{-1}$of global average value as per the European Commission (EC) and World Health Organization (WHO)[12,21,22]. The estimated radon inhalation and ingestion doses from water are higher than the recommendations[1,9].

For people of various ages, the ingestion dose was calculated based on annual water intake in order to determine the potential harmful effects of radon on health. Table 2 provides a summary of the calculated total annual ingestion doses to individuals in various age groups. The fact that infants and children drink less water than adults may be the reason why the mean ingestion dose exposure to ^{222}Rn in drinking water is significantly below the UNSCEAR and WHO recommended limit of $100(\mu Svy^{-1})$. The average adult radon ingestion dosage exposures were a little bit higher than the UNSCEAR and WHO-recommended limit[7,10].

Table 2. Annual effective dose equivalent estimated due to ingestion of radon in drinking water of different age groups

Life Stage	Age Group	DWI(L/day)	(Annual Effective Ingestion Dose(μSvy^{-1}))				
			Min	Max	GM	Avg.	SD
Infants	0-6months	0.7	3.45	75.14	24.99	32.10	18.38
	7-12months	0.8	3.94	85.87	28.56	36.68	21.00
Children	1-3	1.3	6.41	139.54	46.41	59.61	34.13
	4-12	1.7	8.38	182.48	60.69	77.95	44.63
Males	9-13	2.4	11.84	257.62	85.68	110.04	63.00
	14-18	3.3	16.28	354.23	117.81	151.31	86.63
	Adults	3.7	18.25	397.17	132.09	169.65	97.13
Females	9-13	2.1	10.36	225.42	74.97	96.29	55.13
	14-18	2.3	11.35	246.89	82.11	105.46	60.38
	Adults	2.7	13.32	289.83	96.39	123.80	70.88
Pregnancy	17-18	3	14.80	322.03	107.10	137.55	78.75
	19-50	3	14.80	322.03	107.10	137.55	78.75
Lactation	14-18	3.8	18.75	407.91	135.66	174.23	99.75
	19-50	3.8	18.75	407.91	135.66	174.23	99.75

4 Conclusion

Airborne radon is a significant source of natural radiation. Because it dissolves quickly in water, it poses a risk of radiation exposure. In places with granite deposits, high quantities of radon are found in the water. Water seeping through ore deposits carries away Radon and Radium generated by the decay of Uranium found in Granite, and it ends up in well water. The radon concentration in (^{222}Rn) all samples actually utilized by the residents of the study area is higher than the USEPA proposed maximum contamination threshold of $11Bql^{-1}$, according to previous study[16]. It is clear from this study that 75 percent of bore well and hand pump water samples contain radon values of more than $11Bql^{-1}$. The entire study area's annual effective dose equivalent value is very much less than the safe limit of 100 μSvy^{-1} [7,12,22]. The exposure to radon from drinking water will not pose any health effects to the public of the study area. When compared to lung tissues exposed to airborne waterborne radon by breathing, the annual effective dose equivalent absorbed by stomach walls through ingestion was much lower. Therefore, there is no need for additional treatment because the water is fit for drinking. But the groundwater sources such as Borewell, and Handpump which exceed the maximum contamination limit should be treated with granular activated carbon (GAC) filters (which use activated carbon to remove the radon). Radon exposure has been linked to an increased risk of developing stomach and lung cancer. Additionally, epidemiological studies must be conducted to determine the prevalence of stomach and lung cancer in the research area and other locations of Shankaraghatta where the highest concentration is observed.

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