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Measurement of Radon concentration in water samples collected around Kaveri river basin of old Mysuru region

Sadashivaiah Thimmaiah*, Niranjan Rangapura Shettappa†, Ganesh Kakade Eknath ‡, Yashaswini Thimmappa§, Poojitha Chaluvaiah Gangadhara**, Ningappa Chikkegowda§

Abstract

The present study intends to evaluate the concentration of radon in water samples around the Kaveri River basin of the old Mysuru region, Karnataka. Concentration of radon measurements was done using the Smart RnDuo monitor. The obtained radon concentration of water samples in the study area varied from 0.52 ± 0.1 Bq/l to 99.66 ± 1.59 Bq/l with a geometrical mean value of 6.67 ± 0.27 Bq/l. In this study, 100% of the borewell water samples exceeded the EPA's MCL of 11.1 Bq/l, and 55% of the borewell water samples exceeded the UNSCEAR's MCL of 40 Bq/l. The estimated annual effective dose ranges from 1.43 μSv/y to 272.07 μSv/y, with a geometric mean of 18.20 mSv/y. All surface water samples were below 0.1 mSv/y, and 55% of borewell water samples exceeded the safe limit of 0.1 mSv/y as prescribed by WHO.

Keywords: Radon, Inhalation dose, Ingestion dose, Annual effective dose

1. Introduction

Human beings are perpetually exposed to natural background radiation regardless of their place of stay and livelihood. The natural background

* Department of Physics, Yuvaraja's College, University of Mysore, Mysuru, Karnataka, India; sadashivaiaht69@gmail.com

† Department of Physics, Government Science College, Hassan, Karnataka, India; drniranjanrs@gmail.com

‡ Department of Physics, B.M.S. College of Engineering, Bengaluru, Karnataka, India; drganeshke@gmail.com

§ Department of Physics, Seshadripuram Institute of Technology, Mysuru, Karnataka, India; yashuphy@gmail.com

** Department of Applied Science (Physics), Jain (Deemed-to-be University), Kanakapura Main Road, Ramanagara District, Karnataka, India; poojithacg91@gmail.com

radiation is of two types, namely, terrestrial radiation and extraterrestrial radiation, which arises from cosmic rays reaching the earth from outer space [1]. Terrestrial radiation is due to radionuclides (^{238}U, ^{226}Th and ^{40}K) that are present in variable concentrations in soil, rocks, construction materials and water. Natural ambient radioactivity and the related outdoor gamma radiation exposure are essentially determined by biological and geographical factors. The effect of exposure due to extra-terrestrial radiation is negligible compared to that of terrestrial radiation. The internal exposure is mainly due to radon (^{222}Rn), thoron (^{220}Rn) and their daughter products. ^{222}Rn is the decay product of the ^{238}U chain, and ^{220}Rn is the decay product of the Th^{226} decay chain. Radium (^{226}Ra) emanates an alpha particle and becomes radon (^{222}Rn), and Radium (^{224}Ra), after emission of an alpha particle, become thoron (^{220}Rn). ^{222}Rn, ^{220}Rn and their progenies are attached to air particles of the environment and become aerosols, which are inhaled by human beings, causing lung and stomach cancer [2]. The world average annual effective dose (AED) of radiation from all the sources is 2.4 mSv y^{-1}. In that 50% of the dose arises from consumption of ^{222}Rn, ^{220}Rn and their daughter products [3].

Water is the most essential requirement for the existence of all living beings, as hand pumps and borewells are the sources of groundwater. Rivers, lakes, and other bodies of water are sources of surface water. In both cases, water is in contact with radionuclides present in soils and rocks [4]. Rain carries ^{238}U, ^{226}Th and ^{40}K to soil, streams, and rivers as a result of rock weathering. When water flows through rocks and soils, radon present in them gets dissolved and transmitted to the atmosphere. The presence of radon in ground and surface water depends on local geology, soil porosity, and the concentration of radionuclides in rocks and soil [5]. Radon has a longer half-life than Thoron, and it remains in the human body for a longer time after consumption [6-7]. Radon present in water decays into its progenies by emitting alpha particles having high energy, which can cause health risks in the human body. The important progenies of radon are Po^{214} and Po^{218}, which are major alpha emitters having a prominent effect on stomach and lungs cancer [8]. The Stomach is **a**n organ receiving about 90% of the dose due to radon. It has been observed that lung cancer and stomach cancer **are** due to higher concentrations of radon (C_w) in drinking water [9]. USEPA suggested that MCL should be 11 Bq/l for water samples [10].

Several studies were conducted on **the** measurement of radon concentration in water around the world in different geological areas [3-6]. The detailed measurement of radon concentration is available in ICRP and UNSCEAR reports [1, 8]. These committee reports assess completely the work carried out around the world and arrived at the result that **the** average yearly dose received by the individual must be less than 2.4 mSv/y by ICRP and 1 mSv/y by UNSCEAR.

The Kaveri River basin of the old Mysore region is surrounded by granite rocks such as Closepet Granite or Chamundi granites, pink granite, and other major types of rocks found are gneiss and Charnockites [11, 12]. Various studies have revealed that granites, especially pink granites, are associated with higher activity of radionuclides. This region is associated with Agricultural fields, Industrial hubs and Residential areas. Mysore is a Tier-II city; thus, brick industries, stone crushing plants, and granite quarries are active in this region. Due to stone crushing and mining operations, large quantities of fines are produced, and these are heaped at the nearby citations. Fine particles tend to increase outdoor radioactivity. The concentration of radon is proportional to the activities of primordial radionuclides. Hence, to study the epidemiological survey, measurement of Cw plays a pivotal role; thus, around the Kaveri River basin of the old Mysore region in Karnataka State has been undertaken. The present study aims to raise awareness of drinking water use and its potential health risks. The data is also used for India's radon mapping.

2. Geology of the study area

The river Kaveri takes birth at Talakaveri and covers about 800 km before the end of its journey at the Bay of Bengal. The main tributaries joining the river Kaveri are Harangi, Hemavathi, Kabini and Shimsha. The first major tributary of the Kaveri is the Harangi River, which originates in the Western Ghats of Kodagu. Hemavathi River is the largest tributary that originates in the Western Ghats near Ballalarayana Durga in the Chikkamagaluru district. Kabini is the largest tributary from the right bank that originates from the Wayanadu plateau region of Kerala and joins the river Kaveri at Tirumakudalu. The Shimsa River originates at Devarayana Durga Hills and joins the Kaveri at Maddur. Minor rivers joining the river Kaveri are Arkavathi, Lakshmanatirtha and Suhasini. The major soil types present in the river basin are black soils, which occur in patches; red soils are dominant in this area; litter is found in upland areas, and high weathering takes place due to rain; alluvial soils are found in plain regions [11,12]. The types of rocks present are closepet granite and Charnokite, which are the igneous rocks that are widespread in the northern part of the study area. Metamorphic rocks, such as schists and gneisses, are also dominant in this area [11, 12]. The water sampling locations are shown in Figure.1.

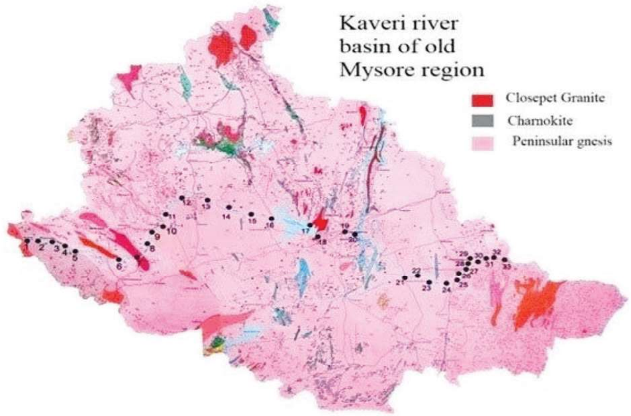

Figure 1: Map depicting sampling locations of the study area (Kaveri River basin of old Mysuru region) [11-12].

3. Materials and Methods

In each location, three samples of water are collected based on the availability after following the prerequisite, such as running the groundwater to flow **for a** few minutes. Water samples from bore wells and surface water bodies at diverse locations of the present study area are collected in leak proof bottles. The Smart RnDuo Monitor has been used to analyse within 2 hours of sample collection. The sample was **placed in a** leakproof, tight bottle with a volume of about 60 ml [13-14]. The experiment was started, radon gas in the experimental setup, including **the** volume of the detector, must be flushed for 5 minutes by putting "pump on" in **the** pump setting screen of Smart RnDuo. Then a fresh scintillation cell was attached **to the** Photomultiplier tube (PMT). Then the sampling bottle and bubbler are connected with a tubing connection, as shown in Figure 2. Then start the monitor with 15-minute cycles and continue the measurement for 60 minutes at an interval of 15 minutes. The concentration of radon in air (C_{air}) is noted down from the monitor. The bubbler kit transfers a major fraction of radon dissolved in the liquid to the air volume of the setup within 1 minute. The transfer fraction is dependent on the air-to-liquid volume ratio (V_{air}/V_{liq}) and the partition coefficient (K) between two media. For more samples to be analyzed the instrument should not be stopped at the end of 60 minutes. A similar process is monitored for continual water sample analysis.

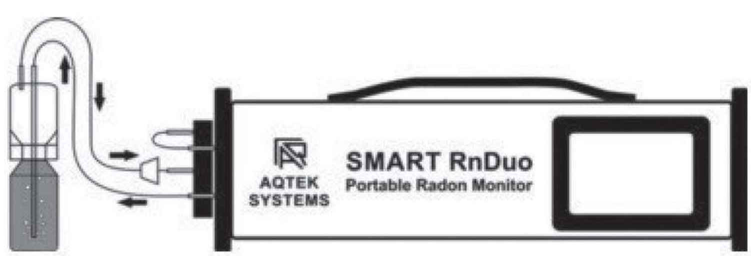

Figure 2: A schematic experimental setup for the measurement of C_w.

The measurements of C_w were carried out in 2024 using the smart RnDuo. Sixty-six samples were collected in thirty-three locations around the Kaveri river basin after preliminary observation of ambient gamma radiation, Cw in groundwater and surface water collected in each location. The measurement of C_w around the Kaveri river basin has been estimated using the relation [15].

$$C_w = C_{air}\,[K + \frac{V_{air}}{V_w}] \tag{1}$$

where K ~0.25 and V_{air}/V_w =5. Radon enters the bodies of living beings through inhalation and ingestion. The AED were calculated using the following relations [16].

$$D_{in} = C_w\, X\, C_{aw}\, X\, FX\, I\, X\, DCF \tag{2}$$

where D_{in} (μSvy^{-1}) is the inhalation dose, C_{aw} is 10^{-4}, *F is* 0.4, *I is* 7000 ha^{-1} and DCF 9nSv(Bqh m^{-3})$^{-1}$[16].

$$D_{ig} = C_w X C_{wt}\, X\, EDC \tag{3}$$

Where D_{ig} is the ingestion dose. C_{wt} is 60 l/y, and EDC is 3.5 nSv/Bq, respectively [16]. AED is the sum of the dose to the lungs and stomach.

4. Results and Discussion

The C_w and AED are tabulated in Table 1. The C_w varied from 0.52 ± 0.15 Bq/l to 99.66 ±1.59 Bq/l, with a geometrical mean value of 6.67± 0.27 Bq/l. The maximum C_w was observed in BWS taken at Krishnaraja Sagara, which is because of the granites at the bedrock [17]. Higher C_w was observed from BWS at Chunchanakatte, Krishnaraja sagara, Srirangapatna, Bannur and Balakvadi. These locations are attributed by closepet granite [18-19]. The intermediate C_w was observed in hand pumps, attributed by Charnokite and peninsular gneiss, **which** contains lower activity [20-21], and the least Cw has been observed in the SWS of Cherangala. This may be due to lesser depth, and radon easily emanates into the atmosphere. The variation of C_w with the locations is due to variation in local geology and geohydrological conditions. [22].

Figure 3 represents the geometrical mean value of C_w in the borewell, hand pump and surface water. **The** Geometrical mean value (GMV) of C_w in **the** borewell is 24.82 Bq/l, hand pump water sample has 14.09 Bq/l and the surface water samples have 2.21 Bq/l.

Among 66 samples 33.3 % (22 samples) showed C_w exceeding the MCL of 11.1 Bq/l as suggested by USEPA [23-24]. it is found that 14 % of water samples have C_w much higher than 40 Bq/l as suggested by UNSCEAR [25]. The measured C_w were compared to the E C suggestions of 100 Bq/l as recommended by WHO [26-27].

As per WHO, if the C_w value is less than 100 Bq/l then the water is good for drinking purpose and no need to take any remedial measures to reduce the C_w in water. In this study almost all samples have C_w value less than 100 Bq/l, so remedial measures is not needed, if C_w values is more than 100 Bq/l then some remedial measures has to be taken. It is always safer to consume borewell water or handpump water after 24 hours, so that the concentration of radon will be reduced drastically to 10% of its initial value at the time of collection of fresh underground water. If water is collected from borewell or handpump are stored in open ventilated tanks for longer time then radon gas escapes naturally and almost 70-90% of radon in water will reduce. Aerate water before use for household purposes is the best method to reduce radon concentration in water.

The variation of D_{in}, D_{ig} and total AED owing to the presence of radon in water samples has been summarized in Table 1. The calculated D_{in} in the studied area varied from 1.32 µSv/y to 251.14 µSv/y with a GMV of 16.80 µSv/y. D_{in} varies from 0.11 µSv/y to 20.93 µSv/y with a GMV of 1.40 µSv/y. The quantity of radon received from lungs ranges from 0.16 µSv/y to 30.11 µSv/y with a GMV of 2.01 µSv/y. The D_{ig} lies in the range of 0.01 µSv/y to 2.50 µSv/y with a GMV of 0.17 µSv/y.

The variation **in** AED with respect to each location is shown in Figure 4. Total AED due to D_{in} and D_{ig} of ^{222}Rn ranges from 1.43 µSv/y to 272.07 µSv/y with a GMV of 18.20 µSv/y. The WHO recommends a reference level for AED of 100 µSv/y [27-28]. Higher annual effective dose has been observed at Chunchanakatte, Krishnaraja Sagara, Srirangapatna, Bannur and Belakavadi is due to diffusion of radon from nearby rocks to water aquifers. In this study all the water samples collected from different locations are having AED less than 100 µSv/y, so no need to take any remedial measures, if the AED is more than the recommended value of WHO biological damage begins, stochastic cancer risk and also lung cancer risk will increase very sharply, higher value of AED damage Bronchial epithelium, lung stem cells chronic inflammation, reduce lung function, chromosomal aberrations, micronuclei formation and somatic mutations [27].

It is always better to keep all windows and doors open in dwellings at least once a week, or whenever possible, so that indoor air exchanges with outdoor air. Hence, the concentration of radon in indoor air decreases. Thus, ingestion and inhalation of radon are reduced.

C_w in the present study area has been compared with different locations in India, and the world scenario is shown in Table 2. Many researchers across the globe have reported that C_w in surface water samples is less than that of ground water samples. In India, the minimum level of Cw was found in surface water and ground water of Hanumangarh district due to lower concentrations of radionuclides in rocks and soil [29]. Maximum C_w in drinking water was found at South Bangaluru district, Karnataka due to the presence of younger granitic plutonic rocks [14]. In globe Iraqi markets drinking bottled water and carbonated beverages had lower C_w is due to aeration of radon into air before filling drinking water bottles and carbonated beverages [30]. Maximum C_w in drinking water was found in groundwater in the Jurassic granite is due to very high uranium concentrations in granite aquifer [31]. All these studies across the globe, clearly indicate that surface water has less C_{Rn} compared to ground water.

Table 1: C_{Rnw} and AED of drinking water in the study area.

Location	Logitude and latitude	Type of water	C_{Rnw} Bq/l Mean ±SD	D_{in} μSv/y	Dose to lungs μSv/y	Dig μSv/y	Dose to The Stomach μSv/y	AED μSv/y
1. Thalakaveri	75° 3' 8'' E, 12° 23' 9'' N	Bore well samples (BWS)	11.81±0.38	29.76	3.57	2.48	0.30	32.24
		Surface water samples (SWS)	0.81±0.17	2.05	0.25	0.17	0.02	2.22
2. Cherangala	75° 30' 59'' E, 12° 22' 47'' N	Hand pump water samples (HWS)	5.14±0.27	12.95	1.55	1.08	0.13	14.03
		SWS	0.52±0.15	1.32	0.16	0.11	0.01	1.43
3. Bhagamadala	75° 31' 49'' E, 12° 23' 6'' N	BWS	5.91±0.27	14.89	1.79	1.24	0.15	16.13
		SWS	1.71±0.15	4.31	0.52	0.36	0.04	4.67
4. Chettimane	75° 34' 30'' E, 12° 22' 41'' N	HWS	5.57±0.15	14.03	1.68	1.17	0.14	15.20
		SWS	2.38±0.18	6.00	0.72	0.50	0.06	6.50
5. Cherambane	75° 37' 11'' E, 12° 22' 17'' N	BWS	8.76±0.17	22.08	2.65	1.84	0.22	23.92
		SWS	5.61±0.25	14.13	1.69	1.18	0.14	15.30
6. Napoklu	75° 41' 15" E, 12° 18' 23" N	HWS	8.26±0.19	20.82	2.50	1.73	0.21	22.55
		SWS	2.88±0.16	7.26	0.87	0.60	0.07	7.86
7. Bettigeri	75° 38' 51" E , 12° 26' 30" N	BWS	9.69±0.17	24.41	2.93	2.03	0.24	26.45
		SWS	0.71±0.18	1.80	0.22	0.15	0.02	1.95
8. Suntikoppa	75° 49' 20"E , 12° 26' 56" N	HWS	11.34±0.34	28.57	3.43	2.38	0.28	30.95
		SWS	5.48±0.16	13.81	1.66	1.15	0.14	14.96
9. Siddapura	75° 48' 16" E , 12° 11' 30" N	BWS	9.29±0.30	23.42	2.81	1.95	0.23	25.37
		SWS	0.78±0.17	1.96	0.23	0.16	0.02	2.12
10. Guddehosur	75° 54' 50''E, 12° 26' 29'' N	HWS	14.08±0.36	35.49	4.25	2.96	0.35	38.44
		SWS	0.72±0.17	1.82	0.22	0.15	0.02	1.97
11. Kaveri Nisragadhama	75° 56' 16'' E, 12° 25' 36'' N	BWS	13.40±0.36	33.78	4.05	2.81	0.34	36.59
		SWS	0.77±0.16	1.93	0.23	0.16	0.02	2.09
12. Kushalnagara	75° 57' 22'' E, 12° 26' 13'' N	BWS	12.99±0.33	32.74	3.93	2.73	0.33	35.46
		SWS	6.31±0.18	15.90	1.91	1.32	0.16	17.22
13. Sirangala	75° 59' 57" E, 12° 33' 47'' N	HWS	9.35±0.28	23.56	2.82	1.96	0.23	25.52
		SWS	0.83±0.27	2.10	0.25	0.17	0.02	2.27

14. Ramanathapura	76° 5' 3" E,	BWS	9.40±0.29	23.68	2.84	1.97	0.24	25.66
	12° 36' 59"N	SWS	0.91±0.16	2.30	0.28	0.19	0.02	2.49
15. Keralapura	76° 10' 26" E,	HWS	7.92±0.28	19.95	2.39	1.66	0.20	21.62
	12° 34' 55"N	SWS	0.88±0.16	2.21	0.26	0.18	0.02	2.39
16. Hanasoge	76° 10' 47" E,	HWS	8.35±0.28	21.03	2.52	1.75	0.21	22.79
	12° 32' 45" N	SWS	0.84±0.17	2.12	0.25	0.18	0.02	2.30
17. Chunchanakatte	76° 17'36"E	BWS	60.13±0.46	151.54	18.17	12.63	1.51	164.17
	12° 30' 7" N	SWS	1.83±0.12	4.61	0.55	0.38	0.05	4.99
18. Krishnaraja Sagara	75° 34' 18''	BWS	99.66±1.59	251.14	30.11	20.93	2.50	272.07
	E,12° 24' 34'' N	SWS	8.76±0.26	22.08	2.65	1.84	0.22	23.92
19. Srirangapatna	76° 40' 58" E,	BWS	61.29±1.44	154.45	18.52	12.87	1.54	167.32
	12° 25' 25"N	SWS	4.59±0.18	11.57	1.39	0.96	0.12	12.53
20. Bannur	76° 51' 43" E,	BWS	55.65±1.24	140.23	16.81	11.69	1.40	151.91
	12° 19' 51" N	SWS	5.50±0.18	13.85	1.66	1.15	0.14	15.00
21. Tirumakudalu	76° 54' 30'' E ,	BWS	28.66±0.58	72.22	8.66	6.02	0.72	78.23
Narasipura	12° 12' 55'' N	SWS	1.24±0.12	3.11	0.37	0.26	0.03	3.37
22. Chowhalli	76° 55' 1" E,	HWS	31.96±0.59	80.53	9.66	6.71	0.80	87.24
	12° 11' 26"N	SWS	4.51±0.14	11.36	1.36	0.95	0.11	12.31
23. Nilsoge	76° 55' 55" E,	BWS	40.02±0.66	100.85	12.09	8.40	1.01	109.25
	12° 11' 57"N	SWS	6.49±0.15	16.35	1.96	1.36	0.16	17.71
24.Madhapura	76° 56' 54" E,	HWS	39.85±0.60	100.43	12.04	8.37	1.00	108.80
	12° 12' 37"N	SWS	4.71±0.14	11.87	1.42	0.99	0.12	12.86
25.Hiriyuru	76° 57' 25" E,	BWS	31.05±0.54	78.26	9.38	6.52	0.78	84.78
	12° 12' 32"N	SWS	5.92±0.14	14.92	1.79	1.24	0.15	16.16
26.Hemmige	77° 0' 18" E	HWS	25.68±0.56	64.72	7.76	5.39	0.65	70.11
	,12° 12' 25"N	SWS	4.61±0.14	11.63	1.39	0.97	0.12	12.60
27.Vadayanadanahalli	76° 58' 5" E,	HWS	27.28±0.59	68.75	8.24	5.73	0.69	74.48
	12° 12' 48"N	SWS	5.91±0.14	14.91	1.79	1.24	0.15	16.15
28.Talakadu	77° 1' 33'' E ,	HWS	41.50±0.68	104.59	12.54	8.72	1.04	113.30
	12° 10' 27'' N	SWS	0.90±0.19	2.27	0.27	0.19	0.02	2.46
29.Kaveripura	77° 6' 12" E,	BWS	42.70±0.65	107.61	12.90	8.97	1.07	116.58
	12° 12' 12"N	SWS	0.71±0.16	1.78	0.21	0.15	0.02	1.93
30. Belakavadi	77° 7' 24" E,	BWS	54.81±1.08	138.13	16.56	11.51	1.38	149.64
	12° 15' 24"N	SWS	6.26±0.17	15.78	1.89	1.32	0.16	17.10
31. Shivanasamudra	77° 10' 38"E,	BWS	45.36±0.68	114.30	13.70	9.52	1.14	123.82
	12° 17' 58"N	SWS	1.66±0.12	4.18	0.50	0.35	0.04	4.53
32. Maruthi temple,	77° 18' 37" E ,	BWS	34.16±0.57	86.09	10.32	7.17	0.86	93.27
Muthathi	12° 18' 26"N	SWS	6.73±0.18	16.95	2.03	1.41	0.17	18.36
33. Sangama	77° 26' 30'' E ,	BWS	47.60±0.69	119.96	14.38	10.00	1.20	129.96
	12° 16' 29'' N	SWS	3.00±0.10	7.57	0.91	0.63	0.08	8.20
Minimum			**0.52±0.10**	**1.32**	**0.16**	**0.11**	**0.01**	**1.43**
Maximum			**99.66±1.59**	**251.14**	**30.11**	**20.93**	**2.50**	**272.07**
Geo. Mean			**6.67±0.27**	**16.80**	**2.01**	**1.40**	**0.17**	**18.20**

Table 2: Comparison of water C_{Rn} in India and World scenario

Location / Region	Type of water sample	Range in C_{Rnw} Bq/ l	Geometrical/ average mean value of C_{Rnw} Bq/ l	Reference
Worldwide				
Nigeria	Drinking water samples(DWS)	1.6 to 271	35.9	[32]
Sudan	Well water samples (WWS)	3.05 to 57.46	14.24	[33]
Iraq	DWS and Carbonated drinks	0.0354 to 0.2480.0354 to 0.283	0.11265 0.1418	[34]
Iran	DW	3.79 to 4.17	-	[35]
Giresun University campus,		76 to 504	193.7	[36]
middle Korea	Ground water samples (GWS)	1.48 to 865.8	211.29	[37]
South Korea	GWS	0.1 to 2393.5	86.6	[37]
Kosovo	Spring water samples (SWS)	0.34 to 341	-	[38]
Bibala	GWS	5.3 to 42	-	[39]
Brazil		0.95-36	36	[40]
Greece		0.8-24	5.4	[41]
Cyprus		0.3-20	5.9	[41]
China		0.71-3735		[42]
Saudi Arabia		0.04–67.44		[43]
India				
Hemavathi River basin	DWS	2.7 to 138.5	25.3	[44]
Haryana, India	DWS	16.06 to 57.35	32.98	[45]
Kabini river basin	GWS	1.1-38.9	8.5	[46]
Rajasthan India	DWS	12.5 to 862	-	[47]
Hanumangarh district,	SWS	0.12 to 2.07	0.62	[29]
India	GWS	1.61 to 8.73	2.24	
Barnala District Punjab, India	GWS	0.17—9.84	3.01	[29]
South Bangaluru district, Karnataka	GWS (Zone A) GWS (Zone B)	-	257 651	[14]
Shimoga district , Karnataka		3.10-38.50	13.60	[48]
Uttara Kannada district (Coastal region)	GWS	2.37- 171.35	22.62	[19]
Ramanagara and tumkur districts , Karnataka	GWS	2.96- 299.06	54.53	[49]
Present study	DWS (GWS and SWS)	0.52 -99.66	6.67	-

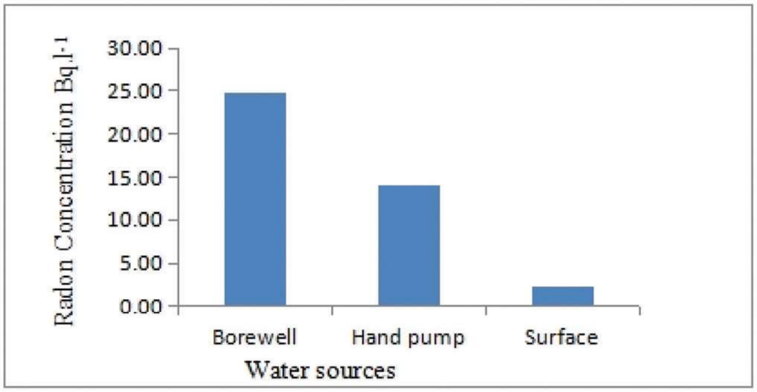

Figure 3: Histogram of C_{Rnw} in BWS, HWS and SWS

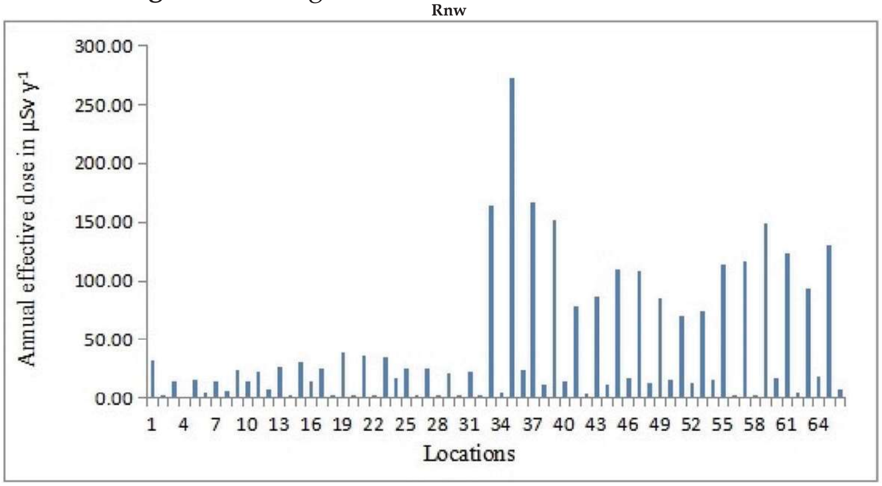

Figure 4: Histogram of the AED of water samples

4.1 Estimation of ingestion dose (age-dependent)

Total annual effective dose (E_{Ing}) received by the stomach due to ^{222}Rn in water for different age groups [16].

$$E_{Ing}(\mu Sv/y) = C_w X DWI X F X T \quad (4)$$

where DWI is daily water consumption, and F is 10^{-8} Sv/Bq and T is 365 days per year, respectively. The annual water intake was used to calculate ingestion doses for people of various ages to identify potential health risks from radon exposure. From Table 3, it is found that adults, pregnant women, and in the Lactation period receive higher ingestion doses. In Infants and Children, the GM value for the ingestion dose received is 17.04 to 19.47 µSv/y and 31.64 to 41.38 µSv/y, respectively, and is comparatively lower than in other age groups due to immature lung tissue. Male adults receive an ingestion dose of 90.07 μSv/y and female adults of 65.73 μSv/y, reason for higher E_{Ing} is fully developed lungs and stable metabolism, enhance ingestion dose to stomach. In the case of Pregnancy and lactation period E_{Ing} is 73.03 and 92.15 μSv/y, this higher value of E_{Ing} is due to more consumption of water, increases in the blood flow to digestive tract, increase in the circulation and volume of body fluid, enhance faster systemic distribution of radon to stomach wall and soft tissue. Consequences on health due to radon exposure by different age groups are different because different age groups have different lung development, breathing rate and metabolism. High dose has been received by adults, Pregnancy and in lactation period leads to DNA stand breakage, high somatic mutations and faster progression of lungs and stomach cancer [25, 49].

Table 3: E_{Ing} due to 222Rn in drinking water [22]

Life stage	Age group in years	DWI (L /day)	E_{Ing} (μSv/y) Min	Max	Geo. Mean (μSv/y)
Infants	0-0.5	0.7	1.32	254.63	17.04
	0.7-0.8	0.8	1.51	291	19.47
Children	1-3	1.3	2.46	472.88	31.64
	4-12	1.7	3.22	618.39	41.38
Males	9-13	2.4	4.55	873.02	58.42
	4-18	3.3	6.26	1200.4	80.34
	Adults	3.7	7.02	1345.91	90.07
Females	9-13	2.1	3.98	763.89	51.12
	4-18	2.3	4.36	836.64	55.99
	Adults	2.7	5.12	982.12	65.73
Pregnancy	19-50	3	5.69	1091.28	73.03
Lactation	19-50	3.8	7.21	1382.28	92.15

4. Conclusions

The data in the present study shows that C_w samples widely varies due to diverse spreading of radionuclides present in granite, Charnokite and gnesis. It is noted that 33.3 % of the water samples have higher C_w than the recommended value of USEPA. The present study shows that higher C_w is present in groundwater than in surface water samples. The geometric mean value of AED due to radon is less than 100 μSv/y, except at a few locations in the study area; hence, the water is safe for consumption and does not require any advanced remedial action. Surface water is safer compared to hand pump and bore well water samples. Since adults consume more water and hence receive higher doses, and also during pregnancy and lactation, a higher ingestion dose is received due to plasma volume increase and faster systemic distribution of radon, leading to a higher risk of lung and stomach cancer.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

Ethical statement

This article does not contain any studies with human participants or animals performed by the author.

Author contribution

Conceptualization: Sadashivaiah Thimmaiah, Niranjan Rangapura Shettappa, Chikkegowda Ningappa. Methodology: Sadashivaiah Thimmaiah, Niranjan Rangapura Shettappa. Data curation: Sadashivaiah Thimmaiah, Niranjan Rangapura Shettappa. Supervision: Chikkegowda Ningappa. Investigation: Sadashivaiah Thimmaiah, Niranjan Rangapura Shettappa. Visualization: Yashaswini Thimmappa, Poojitha Chaluvaiah Gangadhara. Resources: Sadashivaiah Thimmaiah, Niranjan Rangapura Shettappa. Validation: Sadashivaiah Thimmaiah, Niranjan Rangapura Shettappa, Poojitha Chaluvaiah Gangadhara. Writing - Original draft: Sadashivaiah Thimmaiah, Niranjan Rangapura Shettappa. Writing - review & editing: Sadashivaiah Thimmaiah, Niranjan Rangapura Shettappa, Chikkegowda Ningappa, Approval of final manuscript: Chikkegowda Ningappa.

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References

[1]. International Commission on Radiological Protection (1990). Recommendation of the *International Commission on Radiological Protection*. ICRU Publication, 60.

[2]. Baias, P. F., Hofmann, W., Winkler-Heil, R., Cosma, C., & Duliu, O. G. (2010). Lung dosimetry for inhaled radon progeny in smokers. *Radiation protection dosimetry*, *138*(2), 111-118.

[3]. Ramola, R. C., Choubey, V. M., Saini, N. K., & Bartarya, S. K. (1999). Occurrence of radon in the drinking water of Dehradun City, India. *Indoor and Built Environment*, *8*(1), 67-70.

[4]. Voronov, A. N. (2004). Radon-rich waters in Russia. *Environmental Geology*, *46*(5), 630-634.

[5]. Mamun, A., & Alazmi, A. S. (2023). Risk assessment of radon exposure by ingestion and inhalation of groundwater within different age groups. *Groundwater Monitoring & Remediation*, *43*(1), 69-77.

[6]. Bajwa, B. S., Mahajan, S., Singh, H., Singh, J., Singh, S., Walia, V., & Virk, H. S. (2005). A study of groundwater radon concentrations in Punjab and Himachal Pradesh States, India. *Indoor and Built Environment*, *14*(6), 481-486.

[7]. Choubey, V. M., & Ramola, R. C. (1997). Correlation between geology and radon levels in groundwater, soil and indoor air in Bhilangana Valley, Garhwal Himalaya, India. *Environmental Geology*, *32*(4), 258-262.

[8]. United Nations Scientific Committee on the Effects of Atomic Radiation (2000), Effects and risk of ionising radiation, *Report to the General Assembly*, United Nations, New York.

[9]. Henshaw, D. L., Eatough, J. P., & Richardson, R. B. (1990). Radon as a causative factor in induction of myeloid leukaemia and other cancers. *The Lancet*, *335*(8696), 1008-1012.

[10]. USEPA (1991). Federal Register 40 parts 141 and 142; National primary Drinking Water regulations; Radionuclides; proposed Rule (U.S. Environmental Protection Agency). *U.S. Government Printing Office.*

[11]. Sharma, A., & Rajamani, V. (2001). Weathering of charnockites and sediment production in the catchment area of the Cauvery River, southern India. *Sedimentary geology*, *143*(1-2), 169-184.

[12]. Cauvery, t. N. (2020). Geochemical appraisal of sediments from river cauvery, tamil nadu: an insight into its sediment maturity, provenance, and tectonic setting 11(2), 1-10.

[13]. Keesari, T., Mohokar, H. V., Sahoo, B. K., & Mallesh, G. (2014). Assessment of environmental radioactive elements in groundwater in parts of Nalgonda district, Andhra Pradesh, South India using scintillation detection methods. *Journal of Radioanalytical and Nuclear Chemistry*, *302*(3), 1391-1398.

[14]. Poojitha, C. G., Sahoo, B. K., Ganesh, K. E., Pranesha, T. S., & Sapra, B. K. (2019). A model to predict ^{238}U in aquifer rock based on ^{222}Rn and ^{226}Ra measurement in groundwater samples: a case study at South Bengaluru city, Karnataka, India. *Radiation Protection Dosimetry*, *185*(1), 58-66.

[15]. Raghavayya, M., Iyengar, M. A. R., & Markose, P. M. (1979, January). Estimation of radium-226 by emanometry. In *Safety aspects in nuclear fuel cycle: Sixth IARP conference, Bhabha Atomic Research Centre, Bombay, March 7-9, 1979-Programme and synopses* (No. INIS-mf--5372, pp. 33-35).

[16]. United Nations Scientific Committee on the Effects of Atomic Radiation, & Annex, B. (2000). Exposures from natural radiation sources. *Cosmic rays*, *9*(11).

[17]. Naqvi, S. M., Sawkar, R. H., Rao, D. S., Govil, P. K., & Rao, T. G. (1988). Geology, geochemistry and tectonic setting of Archaean greywackes from Karnataka nucleus, India. *Precambrian Research*, *39*(3), 193-216.

[18]. Srinivasa, E., Rangaswamy, D. R., Suresh, S., Nagabhushana, S. R., Sannappa, J., & Umehsareddy, K. (2018). Measurement of radon concentration in drinking

water and estimation of radiation dose to the publics of Hassan city, Karnataka, India. *Radiation Protection and Environment*, *41*(3), 132-135.

[19]. Sannappa, J., Suresh, S., Rangaswamy, D. R., & Srinivasa, E. (2020). Estimation of ambient gamma radiation dose and drinking water radon concentration in coastal taluks of Uttara Kannada district, Karnataka. *Journal of Radioanalytical and Nuclear Chemistry*, *323*(3), 1459-1466.

[20]. Choubey, V. M., Bartarya, S. K., Saini, N. K., & Ramola, R. C. (2001). Impact of geohydrology and neotectonic activity on radon concentration in groundwater of intermontane Doon Valley, Outer Himalaya, India. *Environmental Geology*, *40*(3), 257-266.

[21]. Suresh, S., & Srinivasa, E. (2022). Study on Estimation of Inhalation and Ingestion Dose due to 222 Rn Concentration in Different Types of Ground Water of Some Taluks of Uttara Kannada District, Karnataka, India. *Journal of Scientific Research*, *14*(3), 891-900.

[22]. Suresh, S., Rangaswamy, D. R., Srinivasa, E., & Sannappa, J. (2020). Measurement of radon concentration in drinking water and natural radioactivity in soil and their radiological hazards. *Journal of radiation research and applied sciences*, *13*(1), 12-26.

[23]. Bakac, M., & Kumru, M. N. (2000). Distribution of radionuclides in sediments, soils and waters along Gediz River. *Turkish Journal of Nuclear Sciences*, *27*.

[24]. EPA, U. (1999). Radon in drinking water health risk reduction and cost analysis. *Fed Reg*, *64*(38), 9560-9599.

[25]. United Nations Scientific Committee on the Effects of Atomic Radiation. (2010). Sources and effects of ionizing radiation, united nations scientific committee on the effects of atomic radiation report, volume I: *Report to the general assembly, with scientific annexes A and B-sources*. United Nations.

[26]. Committee, S. (2004). Directive 2001/82/EC of the European Parliament and of the Council of 6 November 2001 on the Community code relating to veterinary medicinal products. *Official Journal L*, *311*(28/11), 1-66.

[27]. World Health Organization. (2004). *Guidelines for drinking-water quality* (Vol. 1). World health organization.

[28]. European Commission (2001) Commission recommendation of 20th December 2001 on the protection of the public against exposure to radon in drinking water. Euratom, 982/ L344/85.

[29]. Singla, A. K., Kanse, S., Kansal, S., Rani, S., & Mehra, R. (2023). A comprehensive study of radon in drinking waters of Hanumangarh district and the assessment of resulting dose to local population. *Environmental Geochemistry and Health*, *45*(2), 443-455.

[30]. Abojassim, A. A., Kadhim, S. H., Ali Mraity, H. A., & Munim, R. R. (2017). Radon levels in different types of bottled drinking water and carbonated drinks in Iraqi markets. *Water Science and Technology: Water Supply*, *17*(1), 206-211.

[31]. Cho, B. W., & Choo, C. O. (2019). Geochemical behavior of uranium and radon in groundwater of Jurassic granite area, Icheon, Middle Korea. *Water*, *11*(6), 1278.

[32]. Ajiboye, Y., Isinkaye, M. O., Badmus, G. O., Faloye, O. T., & Atoiki, V. (2022). Pilot groundwater radon mapping and the assessment of health risk from heavy metals in drinking water of southwest, Nigeria. *Heliyon*, *8*(2).

[33]. Elzain, A. E. A. (2014). Measurement of Radon-222 concentration levels in water samples in Sudan. *Advances in Applied Science Research*, *5*(2), 229-234.

[34]. Abojassim, A. (2017). Alpha particles concentrations from soil samples of Al-Najaf/Iraq. *Polish Journal of Soil Science*, *50*(2).

[35]. Binesh, A., Arabshahi, H., & Pourhabib, Z. (2011). Radioactivity and dose assessment of heavy radioactive pollution, radon and radium from water sources of 3 northern regions in Iran. *Int. J. Phys. Sci*, *6*(35), 7969-7977.

[36]. Büyükuslu, H., Özdemir, F. B., Öge, T. Ö., & Gökce, H. (2018). Indoor and tap water radon (222Rn) concentration measurements at Giresun University campus areas. *Applied Radiation and Isotopes*, *139*, 285-291.

[37]. Cho, B. W., Kim, H. K., Kim, M. S., Hwang, J. H., Yoon, U., Cho, S. Y., & Choo, C. O. (2019). Radon concentrations in the community groundwater system of South Korea. *Environmental monitoring and assessment*, *191*(3), 189.

[38]. Marković, S., Vučković, B., Nikolić-Bujanović, L., Kurilić, S. M., Todorović, N., Nikolov, J., ... & Đokić, B. (2020). Heavy metals and radon content in spring water of Kosovo. *Scientific reports*, *10*(1), 10359.

[39]. Kessongo, J., Bahu, Y., Inácio, M., Peralta, L., & Soares, S. (2020). Radon concentration potential in Bibala municipality water: Consequences for public consumption. *Radiation Physics and Chemistry*, *173*, 108951.

[40]. Marques, A. L., Dos Santos, W., & Geraldo, L. P. (2004). Direct measurements of radon activity in water from various natural sources using nuclear track detectors. *Applied radiation and isotopes*, *60*(6), 801-804.

[41]. Nikolopoulos, D., & Louizi, A. (2008). Study of indoor radon and radon in drinking water in Greece and Cyprus: implications to exposure and dose. *Radiation Measurements*, *43*(7), 1305-1314.

[42]. Zhuo, W., Iida, T., & Yang, X. (2001). Occurrence of ^{222}Rn, ^{226}Ra, ^{228}Ra and ^{238}U in groundwater in Fujian Province, China. *Journal of environmental radioactivity*, *53*(1), 111-120.

[43]. Alabdula'aly, A. I. (2014). Occurrence of radon in groundwater of Saudi Arabia. *Journal of environmental radioactivity*, *138*, 186-191.

[44]. Niranjan, R. S., Ningappa, C., & Yashaswini, T. (2018). Concentration of radon in dwellings of Hemavathi river basin, Karnataka, India. *Radiation Protection Dosimetry*, *181*(3), 269-276.

[45]. Singh, P., Singh, P., Singh, S., Sahoo, B. K., Sapra, B. K., & Bajwa, B. S. (2015). A study of indoor radon, thoron and their progeny measurement in Tosham region Haryana, India. *Journal of Radiation Research and Applied Sciences*, *8*(2), 226-233.

[46]. Yashaswini, T., Ningappa, C., Niranjan, R. S., & Sannappa, J. (2020). Radon concentration level in ground and drinking water around Kabini River basin, Karnataka. *Journal of the Geological Society of India*, *95*(3), 273-278.

[47]. Duggal, V., Sharma, S., & Mehra, R. (2020). Risk assessment of radon in drinking water in Khetri Copper Belt of Rajasthan, India. *Chemosphere*, *239*, 124782.

[48]. Rangaswamy, D. R., Srinivasa, E., Srilatha, M. C., & Sannappa, J. (2016). Measurement of radon concentration in drinking water of Shimoga district, Karnataka, India. *Journal of Radioanalytical and Nuclear Chemistry*, *307*(2), 907-916.

[49]. Srilatha, M. C., Rangaswamy, D. R., & Sannappa, J. (2014). Studies on concentration of radon and physicochemical parameters in ground water around Ramanagara and Tumkur districts, Karnataka, India. *Int J Adv Sci Tech Res*, *2*(4), 641-660.