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Paper

Mapping of uranium concentrations in groundwater samples of Davanagere district, Karnataka, India, and assessment of effective dose to the population

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Abstract

The geomorphology, geohydrology, lithology and ecological features of the area influence the uranium content in groundwater. The groundwater samples were collected from 75 locations of Davanagere district, Karnataka, India. Uranium analysis in the water samples was done using LED fluorimeter, based on fluorescence of dissolved uranyl salts. The uranium concentration in water samples varied from 18.41 to 173.21 μg L^{-1} with a geometric mean of 39.69 μg L^{-1}. Higher uranium concentration in groundwater was observed in Harapanahalli and Jagalur taluk of Davanagere district, which falls in the Eastern Dharwar Craton, which is generally known to contain more radioactive minerals than the Western Dharwar Craton. The effective ingestion dose and lifetime cancer risk to the population were calculated using the obtained uranium concentration in drinking water.

Introduction

Natural radiation exposure is unavoidable for humans. According to the United Nations Scientific Committee on the Effect of Atomic Radiation, exposure to natural sources contributes more than 80% of the total radiation dose to the public[1]. On a global scale, average human exposure from natural sources is 2.4 mSv y^{-1}. Because of its abundance and associated radiological risk, the assessment of uranium is of great interest. Uranium is found in many rock types, like granites, phosphatic rocks, lignite, monazite sands, and also in chemical fertilisers. Uranium transforms through a number of decay modes before reaching the final stable product, ^{206}Pb. The disintegration of uranium isotopes and its daughter products produces alpha or beta and gamma radiations.

Prolonged exposure to uranium through ingestion will raise the risk of renal damage, cancer and heart disease[2, 3]. The kidney and lungs are the primary target organs for uranium chemical toxicity. The experimental evidence suggests that exposures to uranium also affect the respiratory and reproductive systems[4]. An exposure of about 0.1 mg kg^{-1} of body weight, soluble natural uranium, in water causes transient damage to the kidney[5]. Uranium content in groundwater is influenced by the region's lithology, geomorphology and other geological characteristics. Uranium exists in groundwater in dissolved form because of its dissolution from existence of minerals in the aquifer rock, such as uraninite and pitchblende. The present study was carried out to estimate the presence of uranium in groundwater and assessment of associated risk to human health.

Geological settings of the study area

Davanagere district, Karnataka state, India, lies between latitude 14.4644°N and longitude of 75.9218°E at an elevation of 602.5 m above sea level. The large part of the district is located within the Krishna river basin and is drained by Tungabhadra and Chikka Hagari rivers. Janagahalla and Haridra Nandi are two more prominent streams in the area. Davanagere district has a population of 2 704 241[6]. The district is located within the Dharwar craton, and

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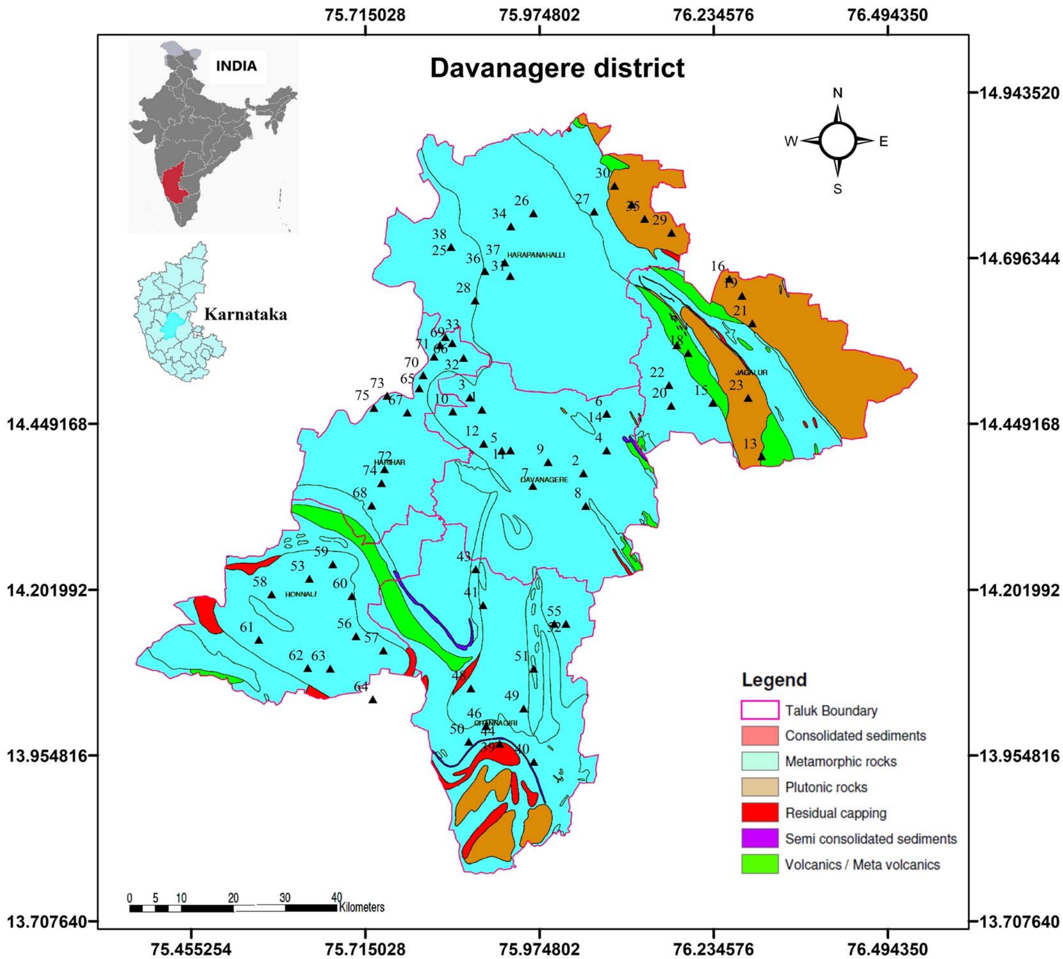

Figure 1. Geological map and sampling stations of Davanagere district.

the geology of the area is quite complex. The rock formations are mainly crystalline granitic gneisses, granites, low- to medium-grade metamorphosed volcano sedimentary rocks[7, 8]. Schistose rocks are found in taluks of Honnali, Channagiri, Harapanahalli and Jagalur. The majority of the district is covered by granite and granitic gneisses that are stratigraphically Archaean in age. The geological map in Figure 1 indicates that the maximum area is bordered by metamorphic rocks. The sampling locations from Davanagere district are depicted in Figure 1.

Materials and methods

An LED fluorimeter (Figure 2) was used to measure fluorescence of uranyl salts. The uranyl salts exhibit fluorescence that can be detected in the spectral band from 490 to 540 nm. Fluran, a buffer reagent, was used so that several dissolved uranyl species in water samples forms a single form with uniformity and high luminous intensity[9].

Figure 2. LED fluorimeter.

Groundwater samples were collected in polyethylene bottles and labelled with geo coordinates. A few drops of nitric acid were added to the sample to prevent radioactive adsorption and precipitation on the internal surfaces of the container during storage, and to maintain pH around 2. Water samples were filtered in the laboratory using Whatman 42 filter paper, to 5 mL of sample taken in a cuvette, 5% of tetrasodium pyrophosphate was added and was shaken well for uniform mixing[10]. The LED fluorimeter was calibrated prior to measurement using standard uranium solutions, and the background counts were recorded.

The concentration of uranium (μg L^{-1}) in samples was calculated using the following equation

$$C_U = \frac{D_1}{D_2 - D_1}\left(\frac{V_1 C_s}{V_2}\right) \quad (1)$$

where C_U is the concentration of uranium in water (μg L^{-1}); D_1 is the fluorescence counts because of sample; D_2 is the fluorescence counts because of sample and U-standard spiked; V_1 is the volume of U-standard added (mL); V_2 is the volume of sample taken (mL); C_s is the concentration of U-standard solution (μg L^{-1}).
where,

Uranium concentration (Bq L^{-1}) = Measured value (μg L^{-1}) × Conversion Factor (0.0248 Bq μg^{-1}).

Effective doses

The total effective radiation dose was computed considering an average adult who would consume 730 L of water annually (2 L/d). For ^{238}U, World Health Organization (WHO) in its report prescribed Dose Conversion Factors as 4.5×10^{-8} Sv Bq^{-1}[11, 12]. Calculations were made to determine the annual radiation ingestion dose caused by uranium consumption through the drinking water pathway.

$$D_I = C_U \times W_I \times DCF \quad (2)$$

where D_I is the ingestion dose (Sv y^{-1}); C_U is the concentration of uranium (Bq L^{-1}); W_I is the intake water rate (L y^{-1}); DCF is the Dose Conversion Factor (Sv Bq^{-1}).

Using the ICRP dose coefficients and recommended water consumption rates, the radiation dose resulting from uranium ingestion through the drinking water pathway for various age groups was estimated[11]. The water intake rates taken for infants of 0–12 months and children of age 1–8 y, and for adult females (>8 y) and males (>8 y) were considered as 0.7, 1.7, 2.7 and 3.7 L d^{-1}, respectively.

Toxicity from ingestion of uranium in drinking water is because of both radiological and chemical effects. Lifetime cancer risk (LCR) has been assessed because of ingestion of uranium by standard method[11, 13]

$$LCR = C_U \times F_R \quad (3)$$

where LCR is the lifetime cancer risk; C_U is the uranium concentration; F_R is the risk factor (per Bq L^{-1}).

$$F_R = R_{coeff} \times I_w \times T_{exp} \times F_c \quad (4)$$

where R_{coeff} is the risk coefficient (4.40×10^{-11} per pCi); I_W is the ingestion water rate (2 L d^{-1}); T_{exp} is the total exposure duration (23,725 d); F_c is the conversion factor (27 pCi Bq^{-1}).

The chemical toxicity risk, i.e. lifetime average daily dose (LADD) and hazard quotient (HQ), was estimated by using the following equations[14].

$$LADD = \frac{C_U \times R_I \times F_{exp} \times T_{Le}}{T_{avg} \times W_b} \quad (5)$$

where C_U is the uranium concentration (μg L^{-1}); R_I is the water ingestion rate (L d^{-1}); F_{exp} is the exposure frequency (d y^{-1}); T_{Le} is the life expectancy (y); T_{avg} is the average time of exposure; W_b is the body weight (kg).

$$HQ = \frac{LADD}{R_{fd}} \quad (6)$$

where HQ is the hazard quotient; LADD (μg kg^{-1} d^{-1}) is the lifetime average daily dose; R_{fd} is the reference dose.

Results and discussion

The uranium concentration was measured in 75 groundwater samples of Davanagere district using an LED fluorimeter. Uranium concentration, coordinates of the sampling stations and the rock type of the region are shown in Table 1. In Davanagere district, the uranium concentration ranges from 18.41 to 173.21 μg L^{-1} with a geometric mean of 39.69 μg L^{-1}. In Davanagere taluk, the concentration varied from 27.15 to 64.83 μg L^{-1}, in Jagalur taluk, the concentration varied from 22.41 to 121.32 μg L^{-1}, in Channagiri taluk, the concentration ranged from 22.10 to 52.44 μg L^{-1}, Honnali taluk had the concentration values ranging from 22.87 to 53.72 μg L^{-1}, in Harihara taluk, the concentration varied from 18.41 to 67.06 μg L^{-1} and in Harapanahalli taluk, the concentration ranged from 35.47 to 173.21 μg L^{-1}. The taluk wise minimum, average and maximum concentration of uranium in groundwater samples are also shown in Figure 3. The average uranium concentration is higher in Jagalur and Harapanahalli taluks with the values of 61.58 and 73.69 μg L^{-1}, respectively. This area corresponds to the Neoarchean Eastern Dharwar Craton (EDC), which is generally known

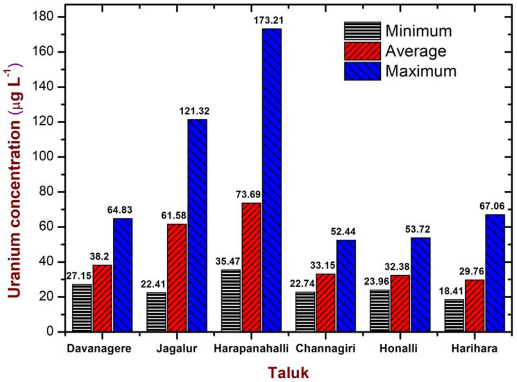

Figure 3. Uranium concentration in Davanagere district.

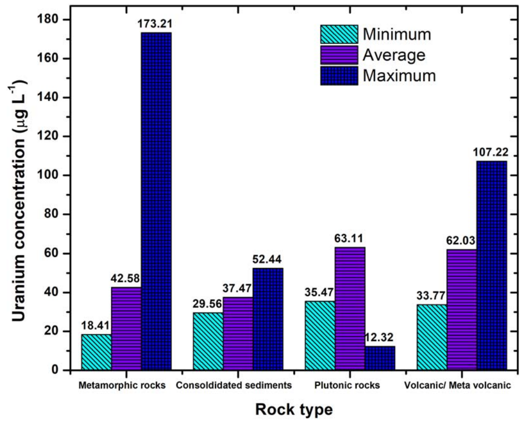

Figure 4. Distribution of uranium in different rock types of Davanagere district.

to contain relatively higher amounts of radioactive minerals than the Western Dharwar Craton (WDC)[15]. It is also known that the eastern parts of Karnataka state (EDC) are dominated by large ion lithophile element-rich K-feldspar granites and gneisses. The western part of Karnataka state (WDC) mainly consists of Mesoarchean tonalite–trondhjemite–gneisses and granitoids[15].

In Davanagere district, all the groundwater samples are not used for the drinking purpose; some of them are used for irrigation and industry. Therefore, to estimate the ingestion dose and radiological risk to the public because of uranium in water, uranium concentration in water samples of bore wells drilled in the villages/-towns were separated and considered. Various health organisations reported concern about the concentration of radionuclide like uranium in drinking water, considering its risk to the human health. The United States Environmental Protection Agency (USEPA)[16] and WHO[12] have set 30 μg L^{-1} as the prescribed concentration level in drinking water and the Atomic Energy Regulatory Board (AERB), India[17], has set a maximum limit of 60 μg L^{-1} for uranium concentration in drinking water. The study area, Davanagere district, includes a substantial agricultural area, and the extensive usage of phosphate fertiliser for crops causes an increase in uranium concentration in soil and water[18].

The range, average and geometric mean values of uranium concentration in groundwater are shown in Table 2. Radiological risk, chemical risk and annual effective dose to the public are also shown in Table 2. The annual effective ingestion dose because of uranium in drinking water varies from 15.00 to 141.11 μSv y^{-1} with a geometric mean value of 34.28 μSv y^{-1}. The Individual Dose Criterion (IDC) set by WHO is 100 μSv y^{-1}[12]. The uranium concentration at two locations in the Harapanahalli taluk exceeded the IDC set by WHO. Exposure to greater levels of uranium adversely impacts public health because of its chemical toxicity combined with internal exposure[11, 19]. The LCR assessment was also carried out to its population and varies from 25.79 × 10^{-6} to 242.70 × 10^{-6} and WHO and USEPA have set a limit value of 8.4 × 10^{-5} for LCR[12, 16, 20]. Sixteen per cent of samples are subjected to high LCR. Chronic exposure to uranium results in renal damage and kidney diseases. The chemical toxicity risk such as LADD and HQ has been estimated. The LADD value varied from 1.42 to 13.36 μg kg^{-1} d^{-1} with a geometric mean of 3.25 μg kg^{-1} d^{-1}, and HQ ranges from 0.32 to 2.98 μg kg^{-1} d^{-1} with an average of 0.83 μg kg^{-1} d^{-1}.

The ingestion doses were calculated for different age groups by considering infants, children, adult male and female (Table 3) and it is clear from the results that the maximum ingestion dose was found in infants which varies from 39.65 to 373.16 μSv y^{-1}. Whereas in children, adult females and adult males, the dose varied from 22.66 to 213.23 μSv y^{-1}, 20.24 to 190.50 μSv y^{-1} and 27.74 to 261.05 μSv y^{-1}, respectively. In the case of infants, the estimated average ingestion dose is above the prescribed IDC of 100 μSv y^{-1} by WHO[4].

The distribution of uranium concentration in different rock types of Davanagere district is shown in Figure 4. Maximum concentration of uranium was observed in the region containing metamorphic rocks. The concentration is also higher in the region covered by Plutonic and Volcanic/meta volcanic types of rocks, whereas in the region with consolidated sediments, lower concentration of uranium was observed.

The frequency distribution of uranium concentration of samples collected from 75 locations is shown in Figure 5. It was found that 15.3% of collected samples are above the AERB guideline of 60 μg L^{-1} and 66.8% of samples exceeded the IDC of USEPA

Table 1. Uranium concentration in groundwater samples of Davanagere district.

Sl. No.	Location	Latitude	Longitude	Types of rock	U conc. (μg L $^{-1}$)
Davanagere taluk					
1	Yaragunte	14.488889	75.898056	M.R.	47.48
2	Anagodu	14.394722	76.044722	M.R.	31.22
3	Avaragolla	14.506944	75.880833	M.R.	35.03
4	Kandanakovi	14.428333	76.078333	M.R.	27.15
5	DVG industrial area	14.428056	75.926944	M.R.	39.98
6	Anaji	14.482778	76.078333	M.R.	64.83
7	Kurki	14.375833	75.971667	M.R.	28.98
8	Kodaganur	14.346667	76.048056	M.R.	45.86
9	Honnur Gollarahatti	14.411111	75.993889	M.R.	29.12
10	Doddabathi	14.486111	75.856111	M.R.	47.75
11	Ramanagara	14.428333	75.939444	M.R.	28.54
12	Shamanur	14.438333	75.900556	M.R.	32.48
Jagalur taluk					
13	Bidarakere	14.419444	76.302222	C.S.	43.52
14	Jagalur	14.482778	76.078333	M.R.	49.21
15	Devikere	14.498889	76.231389	M.R/V.R./M.V.	107.22
16	Sokke	14.683056	76.255556	P.R.	121.32
17	Kenchamma Nagathihalli	14.584444	76.179722	V.R./M.V.	45.10
18	Pallagatte	14.572778	76.195833	V.R./M.V.	33.77
19	Medakeripura	14.657778	76.273611	P.R.	44.00
20	Bilchodu	14.494722	76.171389	M.R.	22.41
21	Hosakere	14.616944	76.288611	P.R.	86.41
22	Asagodu	14.525278	76.168333	M.R.	87.74
23	Baggenahalli	14.506389	76.282500	P.R.	36.75
Harapanahalli taluk					
24	Bennihalli	14.793333	76.114444	P.R.	37.32
25	Neelagunda	14.730278	75.853611	M.R.	50.63
26	Harapanahalli	14.780278	75.972500	M.R.	46.33
27	Nichapura	14.782778	76.060278	M.R.	107.24
28	Telgi	14.650833	75.888333	M.R.	35.97
29	Sasvihalli	14.751389	76.171944	P.R.	110.92
30	Chigateri	14.821111	76.089722	P.R.	35.47
31	Gundagatti	14.687222	75.939167	M.R.	159.78
32	Kondajji	14.565556	75.871667	M.R.	50.03
33	Kurubarahalli	14.596389	75.845278	M.R.	78.91
34	Harapanahalli Polytechnic College	14.760833	75.940000	M.R.	67.42
35	Mattihalli	14.771944	76.133056	P. R	52.25
36	Chirasthahalli	14.694444	75.902500	M.R.	41.53
37	Machihalli	14.707222	75.931111	M.R.	173.21
38	Ittigudi	14.730278	75.853610	M.R.	58.41
Channagiri taluk					
39	Honnebagi	13.993611	75.923889	R.C.	52.44
40	Pandomatti	13.966944	75.973056	M.R.	37.77
41	Karekatte	14.199444	75.899722	M.R.	49.64
42	Santhebennur	14.171667	76.002778	M.R.	22.10
43	Thyavanige	14.252778	75.889167	M.R.	38.03
44	Kerebilachi	13.993611	75.923889	M.R.	22.74
45	Basavapatna	14.199444	75.815278	M.R.	27.52
46	Ajjihalli	14.020000	75.904167	M.R.	29.23
47	Channagiri	14.234167	75.929720	M.R.	32.20
48	Nallur	14.075833	75.882222	R.C.	30.40

(continued)

Table 1. Continued.

Sl. No.	Location	Latitude	Longitude	Types of rock	U conc. (μg L $^{-1}$)
49	Garaga	14.046111	75.958333	M.R.	37.29
50	Yarehalli	13.996667	75.879167	M.R.	33.60
51	Devarahalli	14.105000	75.972778	M.R.	26.05
52	Channapura	14.171667	76.019444	M.R.	25.18
Honnali taluk					
53	Honnali	14.238611	75.649167	M.R.	24.56
54	Hosahalli	14.126944	75.716944	M.R.	29.56
55	Surahonne	14.171667	76.019444	M.R.	28.16
56	Sasvehalli	14.153333	75.716389	M.R.	23.96
57	Kyasinakere	14.132222	75.755833	M.R.	53.72
58	Sattur	14.215278	75.594444	M.R.	22.87
59	Masadi	14.260000	75.682778	M.R.	29.58
60	Bevinahalli	14.212778	75.710278	M.R.	29.89
61	Nyamati	14.148056	75.576111	M.R.	41.54
62	Gadekatte	14.106111	75.646667	M.R.	36.91
63	Chilur	14.105278	75.679167	M.R.	33.90
64	Anaveri	14.059722	75.740556	M.R.	33.91
Harihara taluk					
65	Harihara	14.520556	75.807778	M.R.	26.46
66	Belludi	14.587500	75.855278	M.R.	67.06
67	Hanagawadi	14.484444	75.790556	M.R.	28.99
68	Malebennur	14.347222	75.738889	M.R.	18.41
69	Karalahalli cross	14.584722	75.837778	M.R.	30.47
70	Guttur	14.540000	75.813333	M.R.	25.36
71	Sarathi	14.567500	75.829167	M.R.	18.56
72	Jigali	14.400556	75.757500	M.R.	26.89
73	Rajanahalli	14.509444	75.761389	M.R.	33.38
74	Kumbaluru	14.380000	75.753333	M.R.	24.66
75	Thimlapura	14.491389	75.742222	M.R.	28.11

Where M.R. = metamorphic rocks, C.S. = consolidated sediments, P.R. = plutonic rocks, V.R. = volcanic rocks, M.V. = meta volcanic, R.C. = residual capping

and WHO (30 μg L^{-1}). The Machihalli village in the Harapanahalli taluk showed the highest concentration (173.21 μg L^{-1}), whereas Malebennur in the Harihara taluk had the lowest (18.41 μg L^{-1}) uranium concentration in groundwater. The uranium activity concentration depends on the geological conditions of the area; the formation of white quartz crystal mineral is abundant in the Machihalli region of Harapanahalli taluk where the highest concentration was found[35]. The principal water-bearing rocks present in Harapanahalli taluk are gneisses and schist's. Rocks that have been worn and broken contain groundwater. Groundwater exists in underwater-table conditions and semi-confined areas.

A comparison of uranium concentration in different parts of the world with the present study has been made and is shown in Table 4. Srinivasan *et al.* have reported the concentration of uranium in groundwater of 73 villages of Karnataka and found 48 villages exceed the AERB level of 60 μg L^{-1}. Their study shows that five districts have very high uranium concentration of >1000 μg L^{-1}, and 11 districts exceeded the WHO and AERB recommended level of 30 μg L^{-1}.

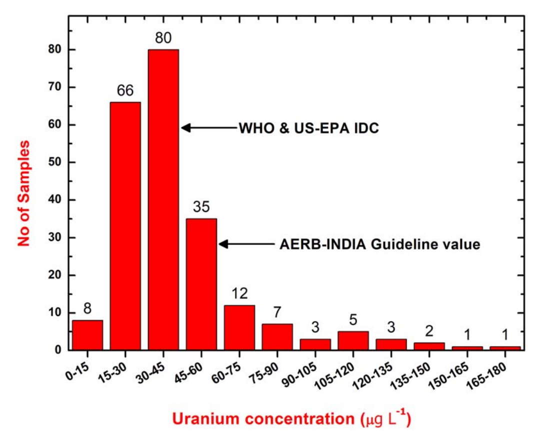

Figure 5. Frequency distribution of uranium concentration in water samples of Davanagere district.

They explain that red loam with laterite soil has a higher degree of oxidation during weathering and oxidation of uranous to uranyl ion occurrence. This process leads to a higher concentration of dissolved uranium in groundwater. The variations in uranium

Table 2. Uranium concentration in groundwater and drinking water samples of Davanagere district and associated radiation risk.

Location	Parameter	Uranium Conc. in groundwater samples	Uranium Conc. in drinking water samples	Radiological risk		Chemical risk	
				Annual effective dose	LCR	LADD	HQ
		μg L $^{-1}$	μg L^{-1}	μSv y^{-1}	$\times 10^{-6}$	μg kg^{-1} d^{-1}	μg kg^{-1} d^{-1}
Davanagere taluk	Range	27.15–64.83	28.54–64.83	23.25–52.82	39.99–90.84	2.20–5.00	0.49–1.12
	Average	38.20	39.59	32.25	55.47	3.05	0.68
	Geo mean	36.84	38.19	31.11	53.51	2.95	0.66
Jagalur taluk	Range	22.41–121.32	45.10–121.32	36.74–98.84	63.19–170.00	3.48–9.36	0.78–2.09
	Average	61.58	82.12	66.90	115.06	6.33	1.41
	Geo mean	54.12	75.98	61.90	106.47	5.86	1.31
Harapanahalli taluk	Range	35.47–173.21	37.47–173.21	28.90–141.11	49.70–242.70	2.74–13.36	0.61–2.98
	Average	73.69	70.18	57.17	98.33	5.41	1.21
	Geo mean	64.01	61.93	50.45	86.77	4.78	1.07
Channagiri taluk	Range	22.74–52.44	22.74–52.44	18.522–42.72	31.86–73.47	1.75–4.05	0.39–0.90
	Average	33.15	33.90	27.62 26.57	47.50	2.62	0.58
	Geo mean	32.07	32.62		45.70	2.52	0.56
Honnali taluk	Range	23.96–53.72	24.56–53.72	20.01–43.76	34.42–75.27	1.89–4.14	0.42–0.93
	Average	32.38	35.33	28.94	49.78	2.74	0.61
	Geo mean	31.45	34.46	28.08	48.29	2.66	0.59
Harihara taluk	Range	18.41–67.06	18.41–33.38	15.00–27.20	25.79–46.78	1.42–2.58	0.32–0.57
	Average	29.76	26.33	21.45	36.89	2.03	0.45
	Geo mean	27.81	25.53	20.08	35.77	1.97	0.44

Table 3. Age-dependent ingestion dose because of uranium in drinking water samples of Davanagere district.

Age group	Annual ingestion dose because of uranium in drinking water (μSv y^{-1})	
	Range	Average
Infants (0–12 months)	39.65–373.16	103.49
Children (1–8 y)	22.66–213.23	59.14
Adult female (> 8 y)	20.24–190.50	52.83
Adult male (> 8 y)	27.74–261.05	72.40

concentration observed worldwide were attributed to the different geological conditions(15). The present study values are lower when compared with those reported by Jindal *et al.*(34), in the granitic region of Eastern parts of Karnataka.

Conclusions

The uranium concentration varied from 18.41 to 173.21 μg L^{-1} with a geometric mean of 39.69 μg L^{-1} in groundwater samples of Davanagere district. Higher concentration was observed in the metamorphic, plutonic and volcanic/meta volcanic rock types. In all, 15.3% of samples showed concentration above the prescribed level of 60 μg L^{-1} by AERB and 66.8% of the samples above the WHO and USEPA guideline value of 30 μg L^{-1}. Higher uranium concentration in groundwater is observed in Jagalur taluk of Davanagere district, this area corresponds to the EDC, which is generally known to contain relatively higher radioactive minerals than the WDC. The annual ingestion dose to the population of Davanagere district because of uranium in drinking water varied from 15.00 to 141.11 μSv y^{-1} with a geometric mean value of 34.28 μSv y^{-1} and LCR varied from 25.76 $\times$ 10^{-6} to 242.69 $\times$ 10^{-6}. The HQ value varies from 0.32 to 2.98 μg kg^{-1} d^{-1}. Even though the average HQ value (0.83) is within the safe limit prescribed by WHO, 20% of the samples exceed the HQ value of 1. People consuming groundwater where uranium concentration is above the maximum contamination limit are prone to radiological and chemical risks. The higher uranium activity is correlated with the geological structure of

Table 4. Comparison of uranium activity concentration with various parts of the world.

Sl. No.	Region	Uranium Conc. (μg L^{-1})	References
1	Central Brazil	0.001–0.308	(21)
2	Churu district of Rajasthan, India	0.68–233	(22)
3	Nalbari district of Assam, India	0.6–10.3	(23)
4	Five districts of Kerala in southern India	0.5–12.54	(24)
5	Parts of Eastern Karnataka	1–5995	(15)
6	Tiruvannamalai, Tamil Nadu, India	0.79–71.93	(25)
7	Pithoragarh district, Uttarakhand, India	0.10–8.32	(26)
8	An-Najaf, Iraq	1.75 – 1.07	(27)
9	Northern Bavaria (Southeastern Germany)	0.325–58.3	(28)
10	Bangalore, Karnataka, India	0.136–2027.5	(29)
11	Vishakhapatnam, Andhra Pradesh, India	0.6–12.3	(30)
12	Bathinda, Punjab, India	0.48–571.7	(20)
13	Central Valley, California, USA	0.04–2500	(31)
14	Great Britain	0.02–48.0	(32)
15	Kodagu, Karnataka	0.4–8.8	(33)
16	Granitic terrain in Eastern parts of Karnataka	2985.7–8649	(34)
17	Mysuru, Karnataka	0.34–242.93	(10)
18	Davanagere district, Karnataka, India	18.41–173.21	Present study

the study area. Concentration of uranium must be monitored periodically to assess the radiological risks to the public.

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