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Mapping of uranium in groundwater of Mysuru district, Karnataka, India and radiation dose to the population

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ABSTRACT

Uranium in ground and surface water may pose significant health hazards, if they are ingested via drinking pathway because of its radiological and chemical toxicities. Higher uranium concentration in drinking water can lead to serious diseases like leukemia, kidney cancer, stomach cancer and renal damages etc. In the present investigation, uranium concentration in groundwater samples of Mysuru district has been studied using an LED fluorimeter. About 350 water samples have been collected covering all the areas of Mysuru district and the uranium concentration varied from 0.34 to 242.93 μg l^{-1}. The age depended dose due to uranium in drinking water has been estimated to evaluate the health hazards. The annual ingestion dose varied from 0.51 to 95.76 μSv y^{-1}. The radiological and chemical toxicity risk to the population due to uranium in water was estimated. The Excess Cancer Risk varied from 1.22×10^{-6} to 102.63×10^{-6}. The mean value of Hazard Quotient 0.07 indicates that the populations are less prone to adverse health effects of uranium contamination in water.

1. Introduction

Uranium, the heaviest naturally occurring radioactive element is widely distributed in natural soil and water in varying quantities across the world. The factors that influence the uranium concentration in natural water are lithology, hydrogeology, geomorphology and other ecological conditions of the region. Even though the main source of uranium in water is geogenic, anthropogenic activities like mining, industries, and agricultural practices are also the source of uranium contamination in water. Uranium exist as a mixture of ^{234}U (0.72 %), ^{235}U (0.0054 %) and ^{238}U (99.275 %) in the earth crust, all of which decay by alpha and gamma emissions [1]. Natural uranium occurs in +2, +3, +4, +5 and +6 valence states among which the most common state is hexavalent form and is generally associated with oxygen as the uranyl ion, UO_2^{2+} [2]. Uranium in hexavalent form is soluble in water and pose radiation dose via ingestion. 75 % of the uranium is ingested through drinking water and the remaining through food sources [3]. Most of the ingested uranium is eliminated by the body through urine and feces but up to 6 % of the ingested uranium can enter the blood stream and gets deposited in bones, kidneys and liver [4]. ^{238}U has a half life of 4.5 billion years, which mean that uranium atoms decay infrequently resulting in a low specific activity. But they are associated with their daughter products like radium, radon and polonium which can pose internal damages by emitting alpha particle during their decay [5]. The major toxicity due to uranium to mankind is chemical toxicity and is affected by the factors such as uranium concentration, exposure frequency, pH, temperature etc. Intake of uranium via drinking pathway can cause stomach and urinary track cancer and also disorders the functions of kidney, leading to renal damages [6]. Various agencies and regulatory boards have set maximum contamination limit of uranium in drinking water to protect public from adverse health effects. 30 μg l^{-1} and 60 μg l^{-1} is the maximum acceptable limit of uranium in drinking water as prescribed by WHO [7] and AERB [8] respectively. People in the study area are depending on ground and surface water sources for drinking purposes, particularly in the rural area. Hence it is important to determine the concentration of uranium distributed in the natural water and to estimate the radiation dose received by the public to bring awareness about uranium concentration and its health effects to local

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population.

2. Study area

The study area is Mysuru district, Karnataka, India that lies between 11°45′–12°40′ N latitude and 75°59′–77°05′ E longitude, at an altitude of about 767 m above the sea level. The district covers an area of about 6269 km^2 and has seven taluks namely Mysuru, Hunsur, H. D. Kote, K. R. Nagar, Nanjangud, Periyapatna and T. Narasipura [9]. The two major rivers of the district are Kaveri and Kabini. Kaveri originate from Madikeri district and Kabini originate from Kerala state. Geomorphologically, 85–90 % of the district falls in the category of denudational uplands. Red sandy soils, red loamy soils and deep black soils are the major soil type in the district. Meta-sedimentary rocks like biotite, schist, mica schist and hornblende schist belonging to Dharwar group are also present as patches. Younger intrusions like felsite, pegmatite and granite are found in the study area which is known to contain higher radioactive minerals [10]. People use both groundwater and surface water for drinking and irrigation purposes.

3. Materials and methods

3.1. Sampling

The groundwater sites were identified in Mysuru district covering all the taluks and water samples of about 500 ml were collected in a pre cleaned glass bottles. GPS of the location were noted and pH of the water samples was measured at the sampling area. These samples were acidified using HNO_3 to avoid precipitation and wall adsorption of radionuclides.

3.2. Sample analysis

To measure the concentration of uranium in water samples, an LED fluorimeter, manufactured by Quantalase Enterprises Pvt. Ltd., India was used (Fig. 3). It is a compact, portable instrument which has most accurate and precise technique to estimate the trace level of uranium in water. The basic working principle is measurement of fluorescence of uranyl salts. Addition of an inorganic reagent converts various uranyl species present in the samples in to a single form that also has uniform and high luminous intensity. Uranyl salts emit fluorescence in the spectral region from 490 nm to 540 nm under UV excitation. The minimum detection limit of this instrument is 0.2 μg l^{-1}. The block diagram of LED fluorimeter is shown in Fig. 2.

For calibration, specific concentration of uranyl nitrate was prepared using a standard stock solution. A standard stock solution of uranyl nitrate was diluted to specific concentrations for regular calibration of the system. Tetrasodium pyrophosphate was used as the fluorescence enhancement agent and for the formation of the uranyl complex. A 5 ml of water sample and 0.25 ml of $Na_4P_2O_7.10H_2O$ was placed in a clean and dry cuvette and fluorescence counts were noted. The concentration of uranium (μg l^{-1}) in samples was calculated using Eq. (1)

$$C_u = \frac{D_1}{D_2 - D_1}\left(\frac{V_1 C}{V_2}\right) \tag{1}$$

Where, C_u is the concentration of uranium in water (μg l^{-1}), D_1 is the fluorescence counts only due to sample, D_2 is the fluorescence counts due to the sample and uranium standard spiked, V_1 is the volume of uranium standard added (ml), V_2 is the volume of the sample taken (ml) and C is the concentration of the uranium standard solution (μg l^{-1}). (0.025 Bq μg^{-1} is the mass to activity conversion factor used to convert μg l^{-1} to Bq l^{-1}) [11].

4. Assessment of ingestion dose due to intake of uranium via drinking water

To assess the ingestion dose due to uranium in water, the bore well waters which are used for drinking purposes are considered. Out of 350 ground water samples 74 % of the samples are used for drinking purposes and the remaining are used for agricultural and other activities.

Ingestion dose to specific age groups due to intake of uranium through drinking water was estimated using Eq. (2) and IAEA specified dose coefficients [12].

$$D_{ig} = C_u \times W \times D_{CF} \tag{2}$$

Where, D_{ig} is the ingestion dose due to uranium in water (Sv y^{-1}), C_u is the concentration of uranium in water (Bq l^{-1}), W is the average water consumption rate by specific age group (l y^{-1}), D_{CF} is the dose coefficient for uranium specific to different age group (Sv Bq^{-1}). The dose coefficient for the infants, children and adults were considered as 3.4×10^{-7} Sv Bq^{-1}, 8.0×10^{-8} Sv Bq^{-1} and 4.5×10^{-8} Sv Bq^{-1} respectively.

5. Risk assessment

5.1. Excess Cancer Risk (ECR)

Risk coefficients (Bq^{-1}) for ingestion of radionuclides via drinking water are expressed as risk of cancer mortality or morbidity per unit activity intake (ECR), defined as the product of risk coefficient and per capita activity intake of radionuclide via ingestion. Carcinogenic risk coefficient is specific to the radionuclide, the environmental medium, and the mode of exposure through that medium [13].

$$ECR = R \times I \tag{3}$$

Where, R is the risk coefficient for uranium in water ($R = 1.13 \times 10^{-9}$ Bq^{-1} for mortality), I is the per capita activity intake of uranium defined as

$$I = C_u \times E_P \times W_A \tag{4}$$

Where, E_P is the exposure period (23,250 days) [14], W_A is the average water consumption rate (4.05 l day^{-1}) [8].

5.2. Lifetime Average Daily Dose (LADD)

If the biological response is described in terms of lifetime probabilities, doses are often expressed as Lifetime Average Daily Doses (LADDs), given by the Eq. (5) [15].

$$LADD = \frac{C_u \times W_A \times E_D}{B_W \times L_T} \tag{5}$$

Where, LADD is the lifetime average daily dose (μg kg^{-1} day^{-1}), W_A is the average water consumption rate (4.05 l day^{-1}), E_D is the exposure duration (63.7 years, i.e. 23,250 days), B_W is the body weight (52.5 kg) for an adult [16], L_T is the life time exposure (23,250 days) [14].

The Hazard Quotient (HQ) is the standard unit for assessing the chemical risk of a particular chemical. It is the ratio of the chronic daily uranium intake to its reference dose ($R_D = 4.48$ μg kg^{-1} day^{-1}) [8]. The HQ is calculated using Eq. (6).

$$HQ = \frac{LADD}{R_D} \tag{6}$$

6. Results and discussion

The concentration of uranium in 350 groundwater samples of Mysuru district were measured using an LED Fluorimeter. The sampling locations are shown Fig. 1. A large number of samples have been analyzed for uranium concentration in groundwater within Mysuru city.

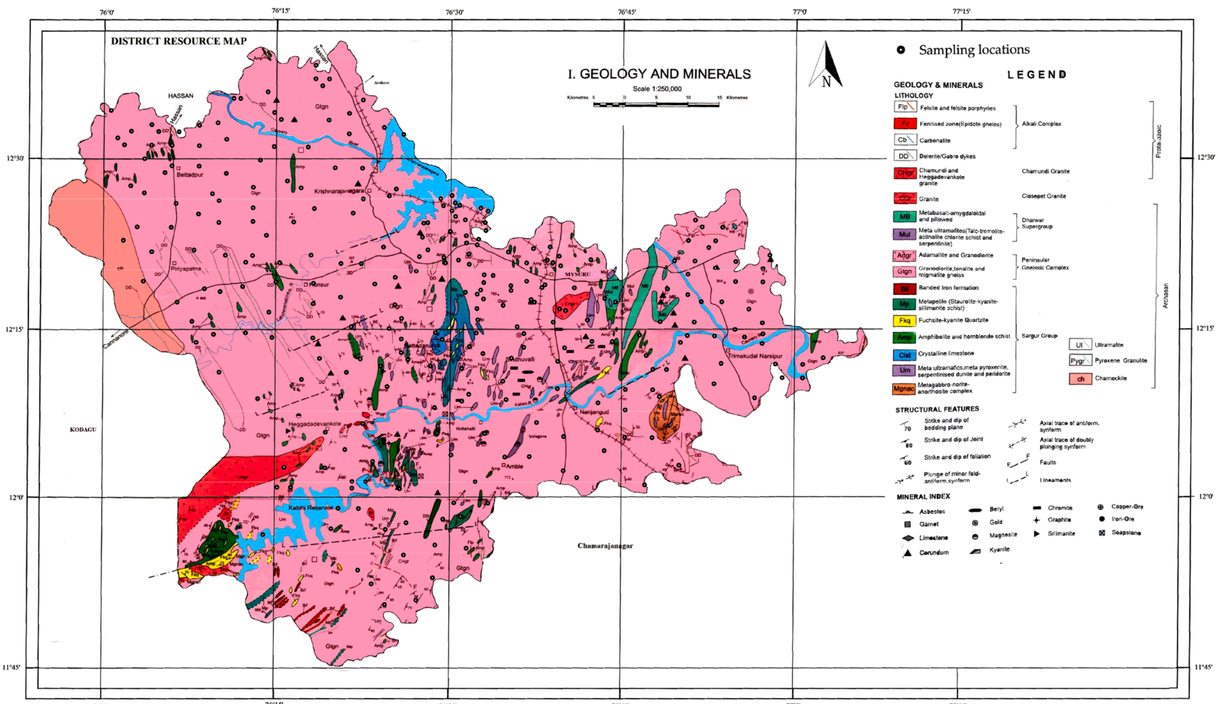

Fig. 1. The study area: Mysuru district.

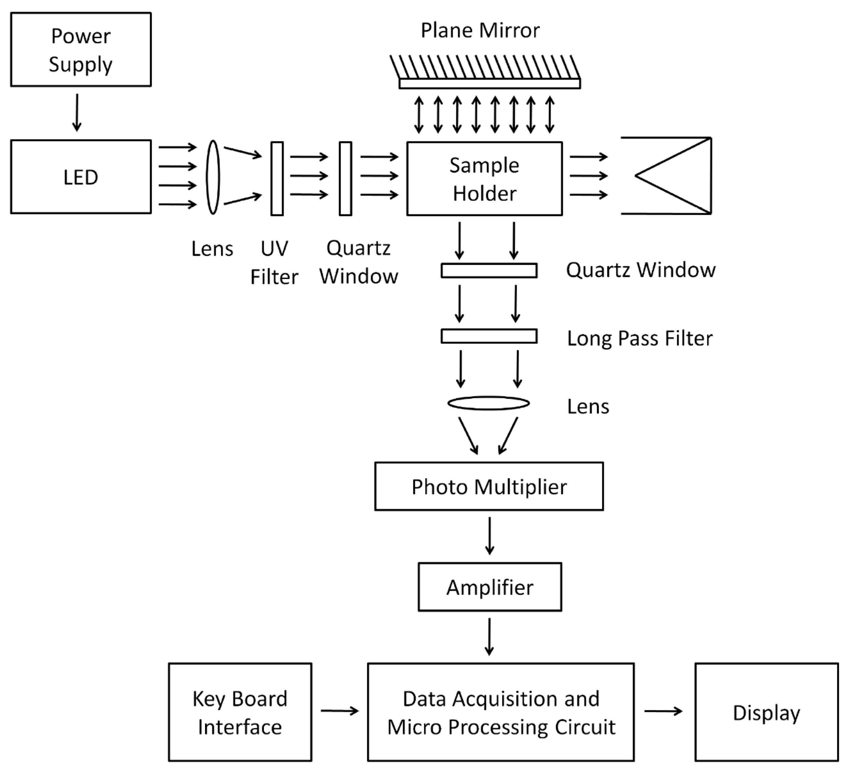

Fig. 2. Schematic diagram of LED fluorimeter.

The minimum, maximum and average uranium concentration in all the groundwater samples of each taluk is shown in Table 1 and Fig. 4. The uranium concentration in groundwater varied from 0.34 to 242.93 μg l^{-1} with a geometric mean of 4.18 μg l^{-1}. Mysuru city and few regions of Mysuru taluk shows higher concentration of uranium in groundwater compared to other regions.

The concentration of uranium in Mysuru city varied from 1.21 to 164.60 μg l^{-1} with a mean value of 17.49 μg l^{-1} whereas in Mysuru taluk the concentration varied from 0.60 to 242.93 μg l^{-1} with a mean value of 9.41 μg l^{-1}. In Mysuru taluk, at Yelwala village higher uranium concentration (242.93 μg l^{-1}) was observed. In this region, higher concentration of ^{226}Ra (74.2 Bq kg^{-1}) in soil samples was observed in the

Fig. 3. LED fluorimeter.

previous study [17]. This indicates the presence of traces of uranium in soil and rock samples of this region. During 2010 to 2012 at one of the locations in Yelwala village of Mysuru taluk, highest uranium concentration of 258.86 μg l^{-1} was observed, however the same bore well showed a lower activity of 26.47 μg l^{-1} when measured during 2023. Similarly at few locations a large variation in uranium concentration in water samples of the same bore wells was observed over a period of 10 years. Anthropogenic activities like industries and use of fertilizers for agricultural purposes are also responsible for higher uranium concentration in groundwater apart from the lithology, hydrogeology and geomorphology of the study area [18].

Uranium concentration of 164.60 μg l^{-1} and 47.20 μg l^{-1} was found in the water samples of Tavarekatte village on the foot hills of Chamundi hill and Bandipalya locality near foot hill of Chamundi hill respectively. The overall concentrations of uranium in bore well samples of Chamundi hill region is higher, but large fluctuations were also observed over a period of 10 years. Higher concentration of uranium in Chamundi hill is attributed to the presence of Chamundi hill granite which is known to contain high activity of radionuclides. The previous studies have shown that Chamundi hill region has higher concentration of ^{226}Ra (70.3 Bq kg^{-1}) in soil samples, ^{226}Ra (189 mBq l^{-1}) in water sample and ^{222}Rn (435 Bq l^{-1}) in water samples compared to other regions of Mysuru [17]. It is also found in the previous studies that Chamundi hill region has higher background natural gamma radiation levels compared to other regions around Mysuru city [19]. The lower concentration of 0.60 μg l^{-1} is found in Bannimantap region of Mysuru city.

The concentration of uranium in H. D. Kote taluk varied from 0.34 to 112.38 μg l^{-1} with an average of 6.10 μg l^{-1}. The presence of granitic rocks known as Heggadadevanakote granite, which are known to contain higher radionuclides may be the reason for higher uranium concentration in water samples of this region. The concentration of uranium in Hunsur taluk varied from 0.57 to 25.28 μg l^{-1} with an average of 5.82 μg l^{-1}. In K. R. Nagara taluk, the uranium concentration varied from 0.51 to 14.62 μg l^{-1} with an average of 4.84 μg l^{-1}. In Nanjangud taluk, the uranium concentration varied from 1.07 to 23.42 μg l^{-1} with an average of 7.02 μg l^{-1}. In T. Narasipura taluk the concentration varied from 0.85 to 10.35 μg l^{-1} with an average 4.12 μg l^{-1}.

The uranium concentration of groundwater from various locations of all the taluks except Mysuru and H. D. Kote taluks are below the recommended limit of 30 μg l^{-1} by WHO [7] and USEPA [20] and 60 μg l^{-1} by AERB [8]. The concentration of only five samples is above 30 μg l^{-1} out of which three samples are above 60 μg l^{-1}.

Out of 350 samples collected in the present study only 74 % of the samples were used for domestic purposes and the remaining was meant for agricultural and industrial activities. Hence to estimate the radiological and chemical hazards to the population, only drinking groundwater samples were considered. The distribution of uranium

Table 1
Uranium concentration and age dependent dose due to uranium in drinking water samples of Mysuru district (2020–23).

Location (Taluks)	Parameter	Uranium concentration in groundwater (μg l^{-1})	Uranium concentration in drinking water (μg l^{-1})	Age dependent ingestion dose (μSv y^{-1}) Infant ($W = 0.8$)	Children ($W = 1.7$)	Adult male ($W = 3.7$)	Adult female ($W = 2.7$)	ECR (10^{-6})	LADD	HQ
Mysuru City	Range	1.21 – 164.60	1.21 – 38.58	3.00 – 95.76	1.50 – 47.88	1.84 – 58.62	1.34 – 42.77	3.22 – 102.63	0.09 – 2.98	0.02 – 0.66
	Average	17.49	5.70	43.41	21.70	26.57	19.39	15.16	0.44	0.10
	Geo. Mean	4.56	3.27	11.95	5.98	7.32	5.34	8.70	0.25	0.06
Mysuru	Range	0.60 – 242.93	0.60 – 26.55	1.49 – 65.90	0.74 – 32.95	0.91 – 40.34	0.67 – 29.44	1.60 – 70.63	0.05 – 2.05	0.01 – 0.46
	Average	9.14	5.51	13.69	6.84	8.38	6.11	14.67	0.43	0.09
	Geo. Mean	4.36	3.94	9.77	4.89	5.98	4.36	10.47	0.30	0.07
H. D. Kote	Range	0.34 – 112.38	0.46 – 12.38	1.14 – 30.73	0.57 – 15.36	0.70 – 18.18	0.51 – 13.37	1.22 – 32.93	0.04 – 0.96	0.01 – 0.21
	Average	6.10	4.01	9.95	4.97	6.09	4.44	10.66	0.31	0.07
	Geo. Mean	3.21	3.06	7.60	3.80	4.65	3.39	8.14	0.24	0.05
Hunsur	Range	0.57 – 25.28	0.57 – 22.41	1.41 – 55.62	0.71 – 27.81	0.87 – 34.05	0.63 – 24.85	1.52 – 59.61	0.04 – 1.73	0.01 – 0.39
	Average	5.82	5.29	13.14	6.57	8.04	5.87	14.08	0.41	0.09
	Geo. Mean	4.24	4.03	10.01	5.00	6.13	4.47	10.73	0.31	0.07
K. R. Nagara	Range	0.51 – 14.62	0.67 – 14.62	1.66 – 36.29	0.83 – 18.14	1.02 – 22.21	0.74 – 16.21	1.78 – 38.89	0.05 – 1.13	0.01 – 0.25
	Average	4.84	5.39	13.39	6.69	8.19	5.98	14.35	0.42	0.09
	Geo. Mean	3.40	3.65	9.07	4.54	5.55	4.05	9.72	0.28	0.06
Nanjangud	Range	1.07 – 23.42	1.55 – 23.42	3.85 – 58.13	1.92 – 29.06	2.35 – 35.58	1.72 – 25.97	4.12 – 62.30	0.12 – 1.81	0.03 – 0.40
	Average	7.02	6.63	16.44	8.22	10.07	7.35	17.62	0.51	0.11
	Geo. Mean	5.34	5.02	12.45	6.23	7.62	5.56	13.35	0.39	0.09
Periyapatna	Range	0.65 – 21.14	0.65 – 14.30	1.61 – 35.49	0.81 – 17.75	0.99 – 21.73	0.72 – 15.85	1.73 – 38.04	0.05 – 1.10	0.01 – 0.25
	Average	6.20	6.11	15.17	7.58	9.28	6.77	16.25	0.47	0.11
	Geo. Mean	4.57	4.75	11.78	5.89	7.21	5.26	12.63	0.37	0.08
T. Narasipura	Range	0.85 – 10.35	0.85 – 10.35	2.11 – 25.69	1.05 – 12.84	1.29 – 15.72	0.94 – 11.47	2.26 – 27.53	0.07 – 0.80	0.01 – 0.18
	Average	4.12	4.09	10.14	5.07	6.21	4.53	10.87	0.32	0.07
	Geo. Mean	3.48	3.40	8.44	4.22	5.16	3.77	9.04	0.26	0.06

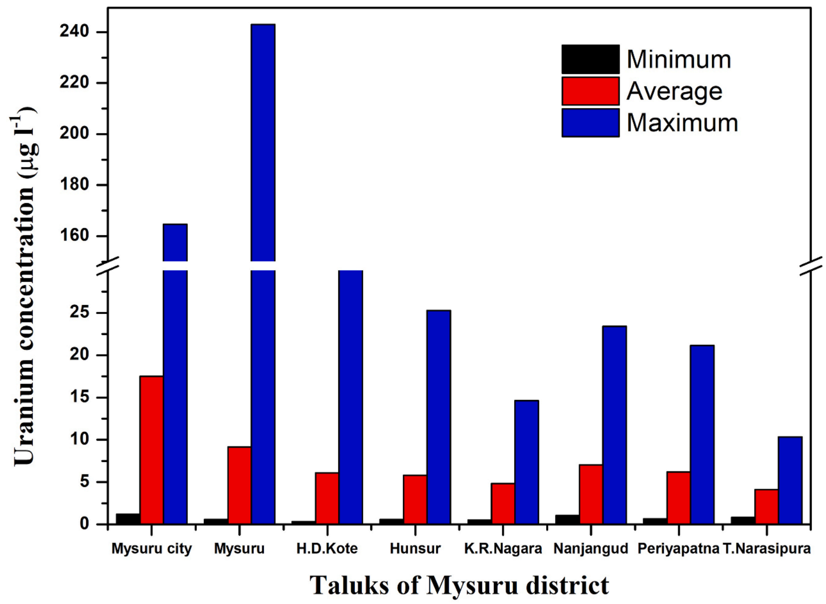

Fig. 4. Distribution of uranium concentration in groundwater samples of Mysuru districts.

concentration in drinking water samples in each taluk and age dependent ingestion dose due to uranium in water is given in Table 1. The ingestion dose varied from 0.51 (adult female) to 95.76 μSv y^{-1} (infant). Even though the infants consume less water, they receive higher radiation dose as they are sensitive to radiation exposure. This can be directly seen from the dose coefficient values for uranium in water prescribed by IAEA [12]. Even though the dose coefficient is same for adult male and female, male adults receive higher radiation dose due to higher intake of water. The ingestion dose lies well within the recommended limit of 100 μSv y^{-1} set by WHO [7] except five samples.

The Excess Cancer Risk was estimated from the measured uranium concentration and risk coefficients. The mortality risk from the uranium concentration in groundwater of the present study was found to vary from 1.22×10^{-6} to 102.63×10^{-6}. All the groundwater samples which are consumed are within the safe limit of 167×10^{-6} prescribed by the Atomic Energy Regulatory Board [8]. Therefore, radiological risk due to uranium concentration in water to the population of the study area can be neglected. The lifetime average daily dose (LADD) varied from 0.04 to 2.98 μg kg^{-1} day^{-1}. The maximum LADD of 2.98 μg kg^{-1} day^{-1} through ingestion of uranium which is computed to assess the risk due to chemical toxicity for the members of the public in the study area is acceptable. Because this is lower than the acceptable reference dose (R_D) of 4.48 μg kg^{-1} day^{-1} prescribed by the AERB [8]. The Hazard Quotient for uranium in drinking water, which is a measure of chemical toxicity of uranium, is calculated from the LADD value. In the present investigation HQ values varied from 0.01 to 0.66 with a mean value of 0.07 which indicate that the chemical health risk due to uranium in drinking water is very less.

The frequency distribution of uranium concentration in groundwater samples of Mysuru district is shown in Fig. 5. Out of 350 samples, 66 % of the samples lie in the range of 0–5 μg l^{-1}. 25 % of the samples lie in the range of 5–10 μg l^{-1}. 6% of the samples lie in the range of 10–15 μg l^{-1}. 2 samples lie in the range of 15–25 μg l^{-1}. Only five samples are above WHO prescribed limit of 30 μg l^{-1} and three samples are above AERB prescribed limit of 60 μg l^{-1}. It can be concluded that, the population of the Mysuru district are less prone to radiological risk due to uranium in

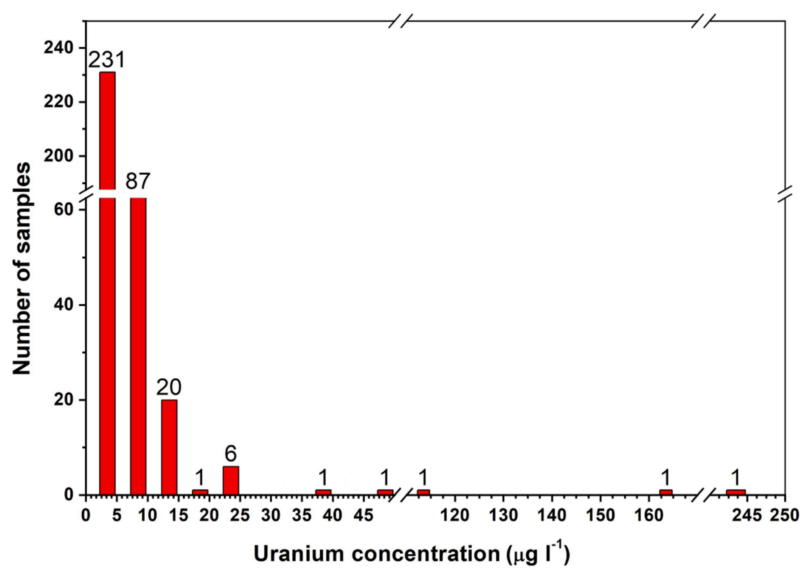

Fig. 5. Frequency distribution of uranium concentration in groundwater samples of Mysuru district.

water.

7. Conclusion

The concentration of uranium in groundwater samples of Mysuru district covering all the taluks varied from 0.34 to 242.93 μg l^{-1}. At only few locations higher uranium concentration of 242.93 μg l^{-1}, 164.60 μg l^{-1} and 112.38 μg l^{-1} is observed and at all other locations the values are in comparable range with the average value 7.59 μg l^{-1}. Out of 350 samples, five samples were above 30 μg l^{-1} (limit prescribed by WHO and USEPA) and three samples were above 60 μg l^{-1} (limit prescribed by AERB). To estimate the ingestion dose, the groundwater which are used for the drinking purpose are considered. The annual ingestion dose due to uranium to different age group varies from 0.51 to 95.76 μSv y^{-1}. The ingestion dose received by the population is less than the recommended limit of 100 μSv y^{-1} by WHO. The value of excess cancer risk, life time average daily dose and hazard index shows that people are less prone to cancer risks from the uranium contamination in drinking water. The population of the Mysuru district is less prone to radiological risk due to uranium in water.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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