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Paper

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Radiation dose due to uranium in groundwater to the population of Chamarajanagar district, Karnataka, India

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Abstract

This paper presents the concentration of uranium in 67 groundwater samples of Chamarajanagar district, Karnataka, India, estimated using an LED fluorimeter. The age-dependent ingestion dose to the population of the district is also studied. The concentration of uranium in groundwater varied from 0.20 to 57.50 μg L^{-1} with an average of 4.40 μg L^{-1}. The annual ingestion dose due to uranium varies from 0.18 to 142.68 μSv y^{-1}, with an average of 7.11 μSv y^{-1}. The ingestion dose received by the population in the study area is less than the recommended level of 100 μSv y^{-1} by the World Health Organization (2011).

Introduction

Uranium is a natural radioactive element, distributed in the Earth's crust at variable concentrations in the form of mineral. ^{234}U, ^{235}U and ^{238}U are the three isotopes of natural uranium, among which ^{238}U is the most abundant with a half-life of 4.5 × 10^{9} years. It is present in granites, metamorphic rocks, lignite, monazite sands and phosphate deposits as well as minerals such as uraninite, carnotite and pitchblende. All of these sources can come in contact with groundwater as a result of weathering and leaching from natural deposits[(1)]. Uranium is found in groundwater, which is being used for drinking purposes in many regions of the world. The amount of uranium mobilized into ground and surface water can change over time, varying with changing oxidizing and alkaline conditions[(2)]. Studies have examined the potential carcinogenicity of uranium as it decays by alpha emission[(3)]. ^{238}U isotope is a parent of radionuclide progenies such as ^{226}Ra, ^{222}Rn and ^{218}Po. Each progeny have unique chemical, mobilization and radioactive properties, which pose inhalation and ingestion doses through different means. Uranium is deposited throughout the body, and the highest levels are found in bone, liver and kidney[(4)]. Uranium compounds that dissolve in water enter the bloodstream through the gastrointestinal tract. Nephritis is one of the primary chemically induced effects of uranium in humans [(5, 6)].

Different nations and regulatory agencies have set various guideline values for the maximum permissible level for uranium in drinking water, i.e. from 2 μg L^{-1} (Japan) to 1700 μg L^{-1} (Russia)[(2)]. The Atomic Energy Regulatory Board (AERB)[(7)], Government of India, has set the guideline value of 60 μg L^{-1} for uranium activity in drinking water. The Bureau of Indian Standards (BIS) has specified a maximum level for uranium concentration in drinking water as 30 μg L^{-1}[(8)]. The World Health Organization (WHO) and U.S. Environmental Protection Agency (USEPA) have set 30 μg L^{-1} as the level for uranium in drinking water [(5, 9)]. Government of India has reported that 151 districts in 18 States of India are partly affected by high (>30 μg L^{-1}) concentration of uranium in groundwater[(10)]. The WHO

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recommends a reference dose level of the committed effective dose, from the consumption of possible total radionuclide in drinking water, which is equal to 0.1 mSv y^{-1} [11].

Depending on the underlying rock formation, some geographical areas naturally contain high levels of uranium. In India, groundwater is being extracted at higher proportion for drinking purposes, and hence, it is essential to estimate the concentration of uranium in groundwater to bring awareness among the local members about its toxicity and harmfulness.

Study area

Chamarajanagar district is located in the southern tip of Karnataka state, India, and lies between the North latitude from 11°40′58″ to 12°06′32″ and East longitude from 76°24′14″ to 77°46′’55″ (Figure 1). The geographical area is about 5101 km^2 and falls in the southern dry zone of Karnataka. The topography is undulating and mountainous with north–south trending hill ranges of Eastern Ghats. The soils of the district are derived from Granitic gneisses, Charnockite rocks, peninsular gneiss and alluvium. Red soil is noticed at the contact of granites and schist, and these are admixtures of sand and silt. Mixed types of soils are localized at places along the contact of schist and other intrusions. Charnockites are widespread formation in Chamarajanagar and Kollegal taluks and part of Yelandur taluk, whereas the entire Gundlupet taluk, parts of Chamarajanagar, Hanur and Yelandur taluks are occupied by gneisses. The major source of water for irrigation and drinking purposes is dug wells, dug cum bore wells and shallow tube wells[12–14].

Materials and methods

The groundwater sources used for drinking purposes were identified and sampled from all five taluks in the study area. At the sampling station, the samples were acidified with nitric acid to avoid precipitation and wall adsorption of uranium. The samples were filtered using Whatman 42 filter paper before analysis for uranium concentration.

Sample analysis

An LED fluorimeter was used for the measurement of uranyl salt concentrations in groundwater (Figure 2). It works on the principle of detection of fluorescence of uranyl complex formed by the addition of an inorganic reagent.

A standard stock solution of uranyl nitrate was diluted to specific concentrations for regular calibration of the system. Sodium pyrophosphate was used as the fluorescence-enhancement agent and for the formation of the uranyl complex because uranyl phosphate complexes are stable. Water sample (5 ml) was placed in a dry and clean cuvette, 0.5 ml of 5% sodium pyrophosphate (pH 7) was added and fluorescence counts were noted. The instrument was calibrated with a standard uranium solution of a known concentration. The concentration of uranium (μg L^{-1}) in water samples was calculated using equation 1 [6].

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

Where C_u is the concentration of uranium in water (μg L^{-1}), D_1 is the fluorescence counts due to the sample, D_2 is the fluorescence counts due to the sample with 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_s is the concentration of the uranium standard solution (μg L^{-1}).

Assessment of radiation dose due to uranium in drinking water

Ingestion dose, due to the intake of uranium, to the people of different age groups through drinking water pathway was estimated using equation (2) [6, 15, 16]. The dose coefficients for specific age group given by IAEA were used for the calculations [6, 16].

$$D_{ig} = C_u \times W \times D_{cf} \quad (2)$$

Where

D_{ig}: Ingestion dose due to uranium in water (Sv y^{-1}).

C_u: Concentration of uranium in Bq L^{-1}.

W: Average water consumption rate by specific age group (L y^{-1})[17].

D_{cf}: Dose coefficient for uranium specific to different age groups (Sv Bq^{-1}).

Mass of U (μg L^{-1}) to the activity of U (Bq L^{-1}) is converted using the factor 0.025 Bq μg^{-1}[2]. The dose coefficient taken for infants of 0–6 months and 7–12 months is 3.4×10^{-7} Sv Bq^{-1}, whereas those for children of 1–3 years and 4—8 years are 1.2×10^{-7} Sv Bq^{-1} and 8.0×10^{-8} Sv Bq^{-1}, respectively. The dose coefficient considered for male and females of age 9–13 years, 14–18 years and > 18 years are 6.8×10^{-8} Sv Bq^{-1}, 6.7×10^{-8} Sv Bq^{-1} and 4.5×10^{-8} Sv Bq^{-1}, respectively[6, 16].

Risk assessment

Excess cancer risk

Risk coefficients (Bq^{-1}) for ingestion of radionuclide via drinking water are expressed as risk of cancer

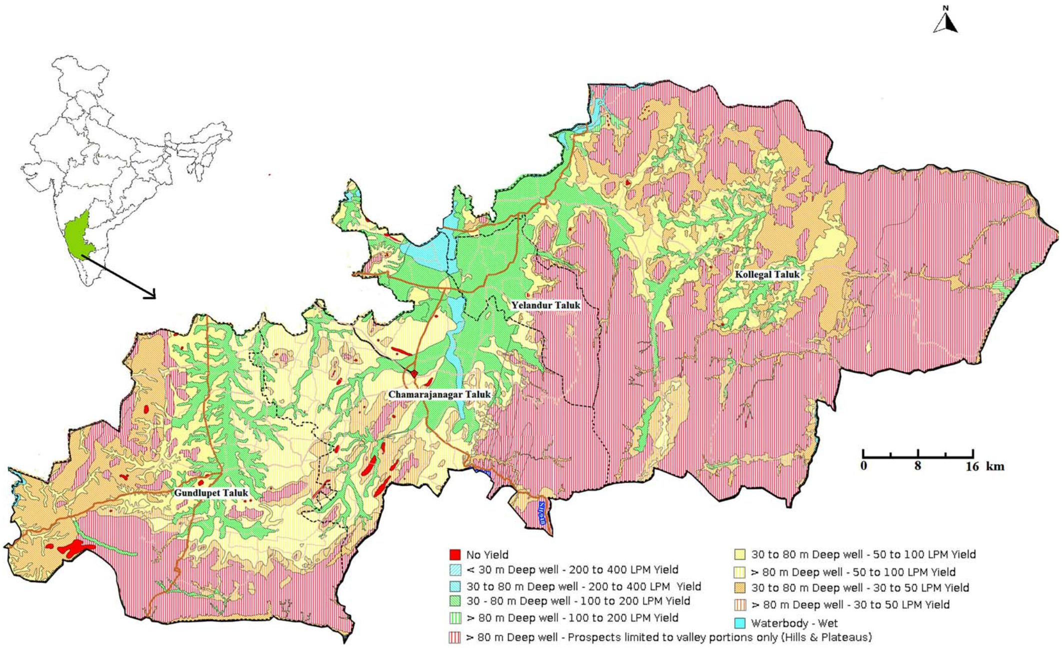

Figure 1. The study area, Chamarajanagar district.

Figure 2. LED fluorimeter.

mortality or morbidity per unit activity intake. Excess cancer risk (ECR) is defined as the product of risk coefficient (r) and per capita activity intake of radionuclide (I) via ingestion. The carcinogenic risk coefficient is specific to the radionuclide, the environmental medium and the mode of exposure through that medium[18].

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

Where r is the risk coefficient for uranium in water ($r = 1.13 \times 10^{-9}$ Bq^{-1} for mortality and $r = 1.73 \times 10^{-9}$ Bq^{-1} for morbidity) and 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)[19] and W_a is the average water consumption rate (4.05 L day^{-1})[7].

Lifetime average daily dose

If the biological response is described in terms of lifetime probabilities, doses are often expressed as lifetime average daily dose (LADD), given by the equation (5)[20].

$$LADD = \frac{C_u \times W_a \times E_d}{B_w \times L_t} \tag{5}$$

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})[7], 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 [21] and L_t is the lifetime exposure (23,250 days)[19].

The hazard quotient

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 ($R_D = 4.48\ \mu g\ kg^{-1}\ day^{-1}$)[7]. The HQ is calculated using equation (6).

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

Results and discussion

The concentration of uranium in groundwater samples collected from five taluks of Chamarajanagar district and associated ingestion dose for specific age groups are given in Table 1. The contour map of uranium concentration is shown in Figure 3. Uranium concentration in water samples varied from 0.20 to 57.50 $\mu g\ L^{-1}$. The maximum concentration of 57.50 $\mu g\ L^{-1}$ is found in Manchahalli village of Gundlupet taluk, which is 13 times higher compared to nearby and average values of the district. No other samples within the radius of 5 km from this location have shown higher values, which is a surprising fact. Higher concentration may be due to higher depth of the bore well where the water has leached from the granitic rock. The minimum concentration is found in villages of Chamarajanagar, Hanur and Gundlupet taluks. Due to uneven topography in the district, the depth of water level changes over a short distance and the concentration of uranium depends on the underlying rock type. The concentration of uranium in the entire samples lies well below the guidance value and only one sample is above the BIS, WHO and USEPA maximum permissible value of 30 $\mu g\ L^{-1}$. The average value of uranium concentration in water samples is 4.40 $\mu g\ L^{-1}$ and lies well within the recommended levels of 30 $\mu g\ L^{-1}$ by the BIS[8], WHO [5] and USEPA[9] and 60 $\mu g\ L^{-1}$ by the AERB [7].

The annual effective dose due to uranium in drinking water to various age-groups is presented in Table 1. The minimum, maximum and average dose values to the population are 0.22 $\mu Sv\ y^{-1}$, 142.72 $\mu Sv\ y^{-1}$ and 7.11 $\mu Sv\ y^{-1}$, respectively, which is lower than the maximum dose level of 100 $\mu Sv\ y^{-1}$ recommended by the WHO[5]. The average annual effective dose to different age groups is shown in Figure 4. It is clear that infants get higher radiation dose compared to other age groups, even though the intake of water is less because of higher dose coefficient values. Women get lesser radiation dose compared to men of the same age group, even with the same dose coefficient due to difference in intake rate of water. The risk associated with uranium in drinking water is shown in Table 2.

The ECR was estimated from the measured uranium concentration and risk coefficients. The ECR from the uranium concentration in water in the present study was found to vary from 0.01×10^{-4} to 1.94×10^{-4} with an average of 0.15×10^{-4}, which is low when compared to an acceptable level of 1.67×10^{-4}[7]. Therefore, radiological risk due to uranium concentration in water to the population of the study area can be neglected. The LADD varied from 0.02 to 4.44 $\mu g\ kg^{-1}\ day^{-1}$. The average LADD of 0.34 $\mu g\ kg^{-1}\ day^{-1}$ 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 as this is lower than the acceptable reference dose (R_D) of 4.48 $\mu g\ kg^{-1}\ day^{-1}$ [7]. The HQ 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 0.99 with an average of 0.08, which indicates that the chemical health risk due to uranium in drinking water is very less.

The frequency distribution of uranium concentration in groundwater of Chamarajanagar is shown in Figure 5. Maximum samples (16) lie in the range of 1–2 $\mu g\ L^{-1}$, 12 samples lie in the range of 3–4 $\mu g\ L^{-1}$. About 81% of the samples lie in the range of 0–5 $\mu g\ L^{-1}$. Eighteen percent of the samples lie within 5–16 $\mu g\ L^{-1}$. Only one sample shows the anomalous value of 57.50 $\mu g\ L^{-1}$, which requires further study.

The uranium concentration in different regions of India is shown in Table 3. Singh et al.[25] have reported that 77 samples out of 157 samples of Bathinda district of Panjab, India, are above 60 $\mu g\ L^{-1}$ with an average value of 84.70 $\mu g\ L^{-1}$.

They found no correlation between depth of water level and uranium concentration, so leaching of uranium from soil to groundwater using phosphate fertilizer may be the reason for the higher concentration of uranium in Bathinda region. Authors conclude that groundwater is not safe for drinking purpose without any treatment [25]. Jindal et al. [29] have reported very high uranium concentrations in the groundwater held in the granitic aquifers in Kolar and Chikkaballapura districts in the eastern part of Karnataka, India[29]. Uranium in water samples were reported as 2985.7 $\mu g\ L^{-1}$ (Kadirampalli village), 5995.2 $\mu g\ L^{-1}$ (Chikkevaripalli village), 3561.3 $\mu g\ L^{-1}$ (Brahmanahalli village), 8649 $\mu g\ L^{-1}$ (G. Madepalli village)[29]. The concentration of uranium in groundwater at Mysuru as reported by Lavanya et al.[6] and Bangalore city by Mathews et al.[15] is 0.34 to 242.93 $\mu g\ L^{-1}$ and 0.136 to 2027.5 $\mu g\ L^{-1}$, respectively. These two cities are nearby to the present study area. The average uranium concentration in groundwater of Mysuru is comparable with the present study region, but the average of Bangalore city stands higher in comparison with the current study area [6, 15]. The values of uranium concentration obtained in the present investigation

Table 1. Activity of uranium and age-dependent ingestion dose due to uranium in groundwater samples of Chamarajanagar district.

Parameter	C_u (μg L^{-1})	Age-dependent dose to the public due to U in water (μSv y^{-1})									
		Infants		Children		Male			Female		
		W = 0.7 0–0.5 Y	W = 0.8 0.6–1 Y	W = 1.3 1–3 Y	W = 1.7 4–8 Y	W = 2.4 9–13 Y	W = 3.3 14–18 Y	W = 3.7 >18 Y	W = 2.1 9–13 Y	W = 2.3 14–18 Y	W = 2.7 >18 Y
Chamarajanagar taluk											
Min	0.50	1.09	1.24	0.71	0.62	0.74	1.01	0.76	0.65	0.70	0.55
Max	15.0	32.58	37.23	21.35	18.62	22.34	30.26	22.79	19.55	21.09	16.63
GM	2.72	5.90	6.74	3.87	3.37	4.04	5.48	4.13	3.54	3.82	3.01
Gundlupet taluk											
Min	0.20	0.43	0.50	0.28	0.25	0.30	0.40	0.30	0.26	0.28	0.22
Max	57.50	124.88	142.72	81.85	71.36	85.63	116.01	87.36	74.93	80.85	63.75
GM	3.06	6.65	7.60	4.36	3.80	4.56	6.18	4.65	3.99	4.31	3.40
Yelandur taluk											
Min	0.20	0.43	0.50	0.28	0.25	0.30	0.40	0.30	0.26	0.28	0.22
Max	14.00	30.40	34.75	19.93	17.37	20.85	28.25	21.27	18.24	19.69	15.52
GM	2.84	6.16	7.05	4.04	3.52	4.23	5.73	4.31	3.70	3.99	3.15
Kollegal taluk											
Min	0.20	0.43	0.50	0.28	0.25	0.30	0.40	0.30	0.26	0.28	0.22
Max	4.50	9.77	11.17	6.41	5.58	6.70	9.08	6.84	5.86	6.33	4.99
GM	1.42	3.09	3.53	2.03	1.77	2.12	2.87	2.16	1.85	2.00	1.58
Hanur taluk											
Min	0.70	1.52	1.74	1.00	0.87	1.04	1.41	1.06	0.91	0.98	0.78
Max	8.10	17.59	20.10	11.53	10.05	12.06	16.34	12.31	10.55	11.39	8.98
GM	2.94	6.39	7.31	4.19	3.65	4.38	5.94	4.47	3.84	4.14	3.26

Min, minimum; Max, maximum; GM, geometric mean; W, water intake by specific age group (L day^{-1}); Y, year.

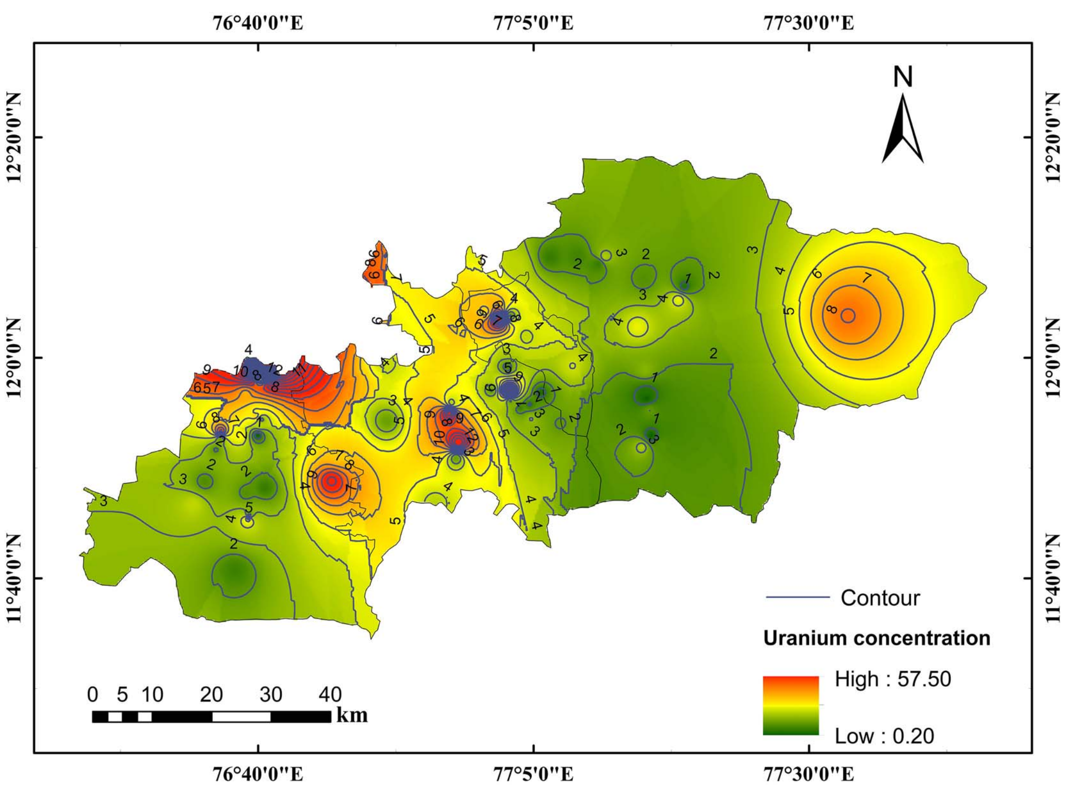

Figure 3. Contour map of uranium concentration in groundwater of Chamarajanagar district.

Table 2. Risk associated with uranium in drinking water of Chamarajanagar district.

Parameter	C_u ($\mu g\ L^{-1}$)	ECR (10^{-4})		LADD $\mu g\ kg^{-1}\ day^{-1}$	HQ
		Mortality	Morbidity		
Minimum	0.20	0.01	0.01	0.02	0.00
Maximum	57.50	1.53	2.34	4.44	0.99
Average	4.40	0.12	0.18	0.34	0.08
Geometric mean	2.46	0.07	0.10	0.19	0.04
Standard deviation	7.38	0.20	0.30	0.57	0.13

Table 3. Uranium concentration in water samples at different regions of India.

Sl. No	Location	Source of water	Range ($\mu g\ L^{-1}$)	Mean ($\mu g\ L^{-1}$)	Reference
1	Punjab and Himachal Pradesh	Hand pumps	1.39–98.25	19.84	(22)
2	Bastar district, Chhattisgarh	Groundwater	0.50–26.4	6.96	(23)
3	Hyderabad	Tap water	0.20–2.50	0.67	(24)
		Groundwater	0.6–82.0	10.07	
4	Bathinda, Punjab	Drinking water	0.48–571.70	84.70	(25)
5	Himachal Pradesh	Drinking water	0.64–29.50	—	(26)
6	Kathua district, Jammu and Kashmir	Drinking water	0.26–21.92	—	(26)
7	Lower Himalayas, India	Groundwater	0.25–17.29	1.97	(27)
8	Bageshwar, Uttarakhand	Drinking water	0.10–28.40	1.6 ± 0.7	(28)
9	Eastern Karnataka, India	Groundwater	2985.5–>8649.0	—	(29)
10	Mysuru, India	Groundwater	0.34–242.93	4.18	(6)
11	Bangalore city, India	Groundwater	0.136–2027.5	92.42	(15)
12	Chamarajanagar, Karnataka, India	Groundwater	0.20–57.50	4.40	Present work

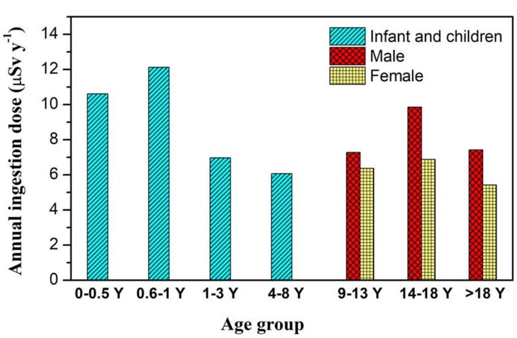

Figure 4. Annual ingestion dose due to uranium in water through drinking pathway for different age groups.

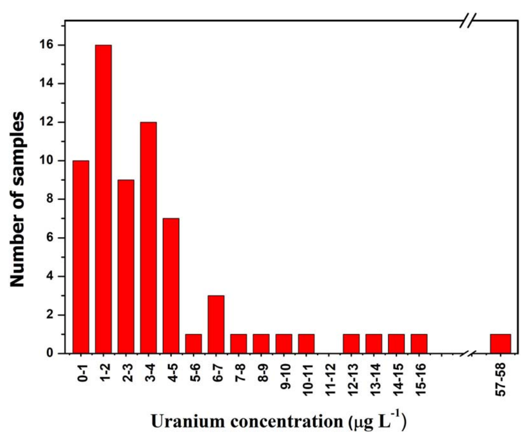

Figure 5. Frequency distribution of uranium concentration in groundwater of Chamarajanagar district.

are, however, lower compared to other reported values across the world.

Conclusions

The concentration of uranium in groundwater samples of Chamarajanagar district covering all the taluks varied from 0.20 to 57.50 $\mu g\ L^{-1}$ with an average of 4.40 $\mu g\ L^{-1}$. At only one location, higher uranium concentration of 57.50 $\mu g\ L^{-1}$ is observed, and at all other locations, the values are in comparable range with the average value. The annual ingestion dose due to uranium for different age groups varies from 0.22 to 142.72 $\mu Sv\ y^{-1}$, with an average of 7.11 $\mu Sv\ y^{-1}$. The ingestion dose received by the population is less than the recommended level of 100 μSv y^{-1} by the WHO. The value of ECR, LADD and hazard index shows that people are less prone to cancer risks from the uranium contamination in drinking water.

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