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2015 J. Radiol. Prot. 35 447

(http://iopscience.iop.org/0952-4746/35/2/447)

IOP Publishing | Society for Radiological Protection Journal of Radiological Protection

J. Radiol. Prot. **35** (2015) 447–455 doi:10.1088/0952-4746/35/2/447

Radiological and chemical toxicity due to ingestion of uranium through drinking water in the environment of Bangalore, India

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Received 19 February 2015, revised 24 March 2015
Accepted for publication 10 April 2015
Published 15 May 2015

Abstract

Groundwater samples collected from 96 bore wells in the study area (city of Bangalore) were analysed for concentration of natural uranium using laser-induced fluorimetry. The risk to the population of the region associated with radiological and chemical toxicity of uranium due to its ingestion through drinking water over a lifetime was estimated. The concentration of uranium was found to be in the range 0.136 to 2027.5 $\mu g\,L^{-1}$ with an average value of 92.42 $\mu g\,L^{-1}$. In the present study, about 61% of the samples show concentrations of uranium within the safe limit of 30 $\mu g\,L^{-1}$ as set by the world health organisation. The radiological risk estimated as lifetime cancer risk is in the range 4.3×10^{-7} to 6.4×10^{-3} with an average of 2.9×10^{-4}. The chemical toxicity risk measured as lifetime average daily dose is found to range from 0.005 to 75.42 $\mu g\,kg^{-1}\,d^{-1}$. The reference dose estimated as 1.12 $\mu g\,kg^{-1}\,d^{-1}$ was used to assess the chemical toxicity. The results indicate that the chemical toxicity due to ingestion of uranium through drinking water is of more concern than the radiological toxicity. The present study, being the first of its kind in this region, will augment the database of uranium in groundwater.

Keywords: uranium, laser fluorimeter, radiological and chemical toxicity, risk, dose

(Some figures may appear in colour only in the online journal)

1. Introduction

Uranium, a long-lived natural radioactive element, is commonly found in rocks, soil, natural materials, food, water and air. It plays an important role in imparting radiation doses to members of the public. Uranium enters the human body mainly through inhalation and ingestion. The concentration of uranium in water is typically very small but varies from region to region depending upon the type of minerals in the soil and bedrock. Uranium gets into drinking water when groundwater dissolves minerals that contain uranium. The world health organization (WHO, 2011) has prescribed the safe limit for uranium in drinking water as $30\,\mu g\,L^{-1}$ [1]. Elevated levels of uranium are more likely to be found in deeper, drilled wells rather than in dug wells or surface water supplies. Studies on this subject have been conducted by various researchers all over the globe. For instance, the concentration of uranium in water samples collected from the Bathinda district of Punjab, India reported by Lakhwant Singh *et al* [2] was found to be in the range 0.48 to $571.7\,\mu g\,L^{-1}$ with a mean value of $84.7\,\mu g\,L^{-1}$. The estimated radiological risk due to the ingestion of uranium through drinking water was reported to be in the range 1.34×10^{-6} to 1.6×10^{-3} with a mean value of 2.37×10^{-4}, whereas the chemical toxicity was found to be in the range 0.04 to $43.11\,\mu g\,kg^{-1}\,d^{-1}$ with a mean value of $6.38\,\mu g\,kg^{-1}\,d^{-1}$. The radiological and chemical risk of uranium in groundwater analyzed by Kim *et al* [3] showed that the excess cancer risks are on the order of 10^{-7}. The hazard quotient in view of the chemical aspect was found to be 0.005. Hence, in their study, an adverse health risk due to the ingestion of uranium was found to be unlikely.

1.1. Health hazards of uranium

Toxicity due to the ingestion of uranium through drinking water is twofold–radiological toxicity, because the element emits radiations of high ionizing power, and also chemical toxicity due to its being a heavy element [4]. Several studies reveal that the kidney is the most susceptible human organ to the toxic effects of uranium [5, 6]. Generally, most uranium in drinking water is eliminated from the body; however, a small amount is absorbed and carried through the bloodstream. Once in the bloodstream, uranium compounds are filtered by the kidneys where they can cause damage to the kidney cells. The chemical effects of uranium in drinking water are of greater concern than the possible effects of radioactivity. In the present study both radiological and chemical toxicity due to the ingestion of uranium through drinking water have been estimated.

1.2. Study area

Bangalore is one of the fastest growing cities in Asia and is located in the southeastern part of Karnataka State, India. It covers an area of $2174\,km^2$ with an average elevation of 900 m above sea level. The soils of the district can be broadly grouped into red loamy and lateritic types. Granites and the peninsular gneissic group constitute the major aquifers in the district [7]. In this region, due to the shortage of treated water, the majority of the population depend on groundwater for their domestic purposes. Since the groundwater is derived from deep granitic and peninsular rocks, it is expected to contain elevated levels of uranium. In recent years, due to rapid and unplanned urbanization and huge growth in population and industrial units, the demand for water has resulted in the indiscriminate drilling of bore wells by individual households, business establishments and industries. This has resulted in depletion of groundwater levels and over-exploitation of the groundwater resources in the district. The deterioration of groundwater quality due to industrial and sewage pollution is the major groundwater problem in this area. Preliminary measurements [8] carried out on the concentration of alpha radioactive nuclides in the groundwater samples show elevated concentrations of uranium and dissolved radon in some locations of the study area. Therefore, to arrive at a robust evaluation of risks to health it was decided to systematically extend the study over a larger area.

The sampling sites in the study area (Bangalore) are shown in figure 1.

2. Experimental methods

Fresh drinking water samples from the bore wells [depth ranges from 90–350 mbgl (metres below ground level)] of the study area were collected from eight study areas, each identified by its compass bearing from Bangalore City railway station. The samples were collected in cleaned and acid washed polythene bottles. All the water samples were filtered through Whatman 42 filter paper. To about of 6 mL of water sample, 1 mL of Fluran (sodium pyrophosphate) was added to obtain fluorescence of all uranyl complexes and analyzed for concentration of natural uranium using a pre-calibrated laser-induced fluorimeter. The annual effective dose and the risk associated with radiological and chemical toxicity of uranium due to its ingestion through drinking water was estimated.

3. Toxicity assessment of uranium

The toxicity associated with the ingestion of uranium is classified as radiological (carcinogenic) and chemical (noncarcinogenic). In the present investigation, the radiological toxicity estimated as the annual effective dose and lifetime cancer risk due to the ingestion of uranium through drinking water was calculated based on the activity concentration of uranium, the average intake of water and the average life span of the population of the region. The risk arising from the chemical toxicity was estimated in terms of lifetime average daily dose (LADD) and hazard quotient (HQ).

3.1. Radiological toxicity

3.1.1. Annual effective dose. The annual effective dose due to the ingestion of uranium through drinking water was calculated as

$$\boldsymbol{D} = \boldsymbol{A} \cdot \boldsymbol{I} \cdot \boldsymbol{F} \tag{1}$$

where $\boldsymbol{D}$ is the annual effective dose due to concentration of uranium in water (μSvy^{-1}), $\boldsymbol{A}$ is the activity concentration of uranium in drinking water (Bq L^{-1}; 1 μg L^{-1} of uranium is equivalent to 0.02528 Bq L^{-1}), $\boldsymbol{I}$ is the annual intake of drinking water (L y^{-1}), equal to 730 L y^{-1} at the rate of 2 L d^{-1} [1], and $\boldsymbol{F}$ is the dose conversion factor for natural uranium via ingestion, 4.63×10^{-8} SvBq^{-1} [obtained as the average of the dose coefficients for ^{234}U, ^{235}U and ^{238}U isotopes based on international commission for radiological protection (ICRP) publications] [9].

The united nations scientific committee on the effect of atomic radiations (UNSCEAR, 2008) has estimated that the global average for annual effective dose per person from all sources of radiation in the environment is approximately 3.0 mSvy^{-1} out of which 2.4 mSvy^{-1} is due to naturally occurring sources of radiation [10]. An individual dose criterion (IDC) of 100 μSvy^{-1} is adopted as a safe limit from the annual consumption of drinking water [1].

3.1.2. Lifetime cancer risk. The lifetime cancer risk was estimated as the product of the risk coefficient and the lifetime effective dose:

Lifetime cancer risk = Risk coefficient (Sv^{-1}) × Lifetime effective dose (Sv),

where

Lifetime effective dose = Annual effective dose (Svy^{-1}) × Average lifespan (years).

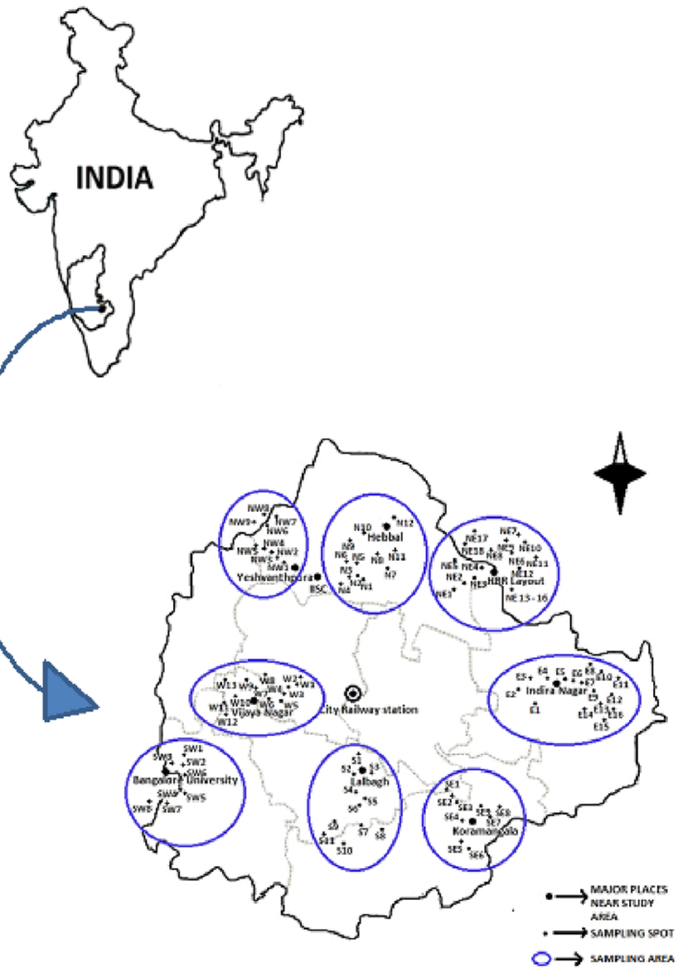

Figure 1. Map showing sampling locations of the study area.

The nominal risk coefficient for radiation-induced cancer incidence is 0.055 Sv^{-1} (ICRP, 2007) [11]. The acceptable level of radiological risk is 10^{-3} [3].

3.2. Chemical toxicity

The chemical toxicity risk due to the ingestion of uranium through drinking water was estimated [12, 13] in terms of lifetime average daily dose (LADD) using the equation

$$\mathrm{LADD}\ (\mu\mathrm{g\ kg^{-1}\,d^{-1}}) = \frac{\mathbf{MC \times IR \times EF \times LE}}{\mathbf{AT \times BW}} \tag{2}$$

where

MC = Mass concentration of uranium (μg L^{-1}),
IR = Ingestion rate of drinking water (L d^{-1}),
EF = Exposure frequency (days per year),
LE = Life expectancy (years),

AT = Average time (days) = Life expectancy (years) × 365,

BW = Average body weight of an Indian person (kg).

The ingestion rate of water (IR) was set as 2 L d^{-1} [1, 14] whereas the exposure frequency (EF) was set as 350 d [14]. The average life expectancy (LE) of an Indian person was taken as 67.8 years [15]. The average time (AT) was 24747 d. The average body weight (BW) of an Indian person was taken as 51.5 kg [16].

The hazard quotient (HQ) was determined using the relation

$$\mathrm{HQ} = \frac{\mathbf{LADD}}{\mathbf{D}_{\boldsymbol{Rf}}} = \frac{\mathbf{MC}}{\boldsymbol{C}_{\mathbf{L}}} \tag{3}$$

where $\boldsymbol{D}_{\mathbf{Rf}}$ is the reference dose, equal to 1.12 μg kg^{-1} d^{-1} which was calculated on the basis of the average daily consumption of water (2 L), and $\boldsymbol{C}_{\mathbf{L}}$ is the limiting concentration of uranium in water (30 μg L^{-1}) [1].

4. Results and discussion

The results obtained in the present study are presented in table1.

4.1. Radiological risk

4.1.1. Annual effective dose. The results obtained for uranium concentration in the groundwater samples collected from the study area show that the overall concentration is in the range 0.136 to 2027.5 μg L^{-1} with a mean of 2.42 μg L^{-1}. About 22% of water samples show very high concentrations of uranium (>120 μg L^{-1}). The observed variation in the concentration can be attributed to the geological features of the study area. The activity concentration of uranium is found to be in the range 3 mBq L^{-1} to 51.26 Bq L^{-1} with a mean of 2.34 Bq L^{-1}. The results obtained in the present study for the concentration of uranium are comparable with the value reported (0.3 to 1442.9 μg L^{-1}) in Kolar and Chikkaballapur [17], districts neighboring Bangalore. The number of samples in the various ranges of concentration of uranium in the specified directions of the study area is shown in figure 2.

The annual effective dose was calculated using equation (1) and is found to be in the range 0.116 to 1732.4 μSvy^{-1} with an average of 78.97 μSvy^{-1}. The safe limit of annual effective dose or individual dose criterion (IDC) from drinking water is 100 μSvy^{-1} [1]. In the present investigation, about 20 samples cross this safe limit and 8 samples show an imparted dose greater than 200 μSvy^{-1}.

4.1.2. Lifetime cancer risk. The radiological risk evaluated as lifetime cancer risk was estimated according to the general ICRP and WHO guidelines. In the present investigation, the overall lifetime cancer risk ranged from 4.3×10^{-7} to 6.4×10^{-3} with a mean of 2.9×10^{-4}. Though the average value in all the directions of the study area is low compared to the acceptable limit of 10^{-3}, the upper end of the range is alarming, which indicates that, with an average intake of water of 2 L d^{-1} over a lifetime with the present uranium level, about 6 to 7 per thousand people of the most exposed population may suffer from uranium-induced cancer. Specifically, the south region of the study area shows highest value of lifetime cancer risk. In the present study, 6 water samples gave a value of radiological cancer risk higher than the acceptable limit.

Table1. Radiological and chemical risks due to ingestion of uranium in groundwater of the study area.

Sampling location (Bangalore)	Parameter	Concentration of uranium (μg L^{-1})	Activity concentration (Bq L^{-1})	Radiological risk: Annual effective dose (μSvy^{-1})	Radiological risk: Lifetime cancer risk	Chemical risk: LADD(μg kg^{-1} d^{-1})	Chemical risk: HQ
North	Range	1.47–941	0.04–23.79	1.25–804.02	4.66×10^{-6}–2.99×10^{-3}	0.05–35.01	0.05–31.25
	Mean	120.76	3.05	103.18	3.84×10^{-4}	4.5	4.01
	Median	15.19	0.38	12.98	4.84×10^{-5}	0.6	0.5
South	Range	5.69–2027.5	0.14–51.26	4.86–1732.4	1.8×10^{-5}–6.4×10^{-3}	0.2–75.42	0.19–67.34
	Mean	265.01	6.7	226.43	8.4×10^{-4}	9.9	8.8
	Median	33.88	0.86	28.95	1.07×10^{-4}	1.3	1.13
East	Range	1.87–402.45	0.05–10.17	1.59–343.87	5.96×10^{-6}–1.28×10^{-3}	0.07–15	0.063–13.67
	Mean	115.56	2.92	98.73	3.68×10^{-4}	4.3	3.84
	Median	24.78	0.63	21.73	7.89×10^{-5}	0.9	0.82
West	Range	1.12–147.6	0.03–3.73	0.957–126.12	3.57×10^{-6}–4.7×10^{-4}	0.04–5.5	0.038–4.9
	Mean	42	1.06	35.88	1.33×10^{-4}	1.6	1.39
	Median	22.17	0.56	18.94	7.06×10^{-5}	0.8	0.73
Northeast	Range	0.136–172.4	0.003–4.36	0.116–147.34	4.3×10^{-7}–5.49×10^{-4}	0.005–6.4	0.005–5.72
	Mean	44.85	1.13	38.33	1.42×10^{-4}	1.7	1.48
	Median	20.35	0.51	17.39	6.48×10^{-5}	0.8	0.67
Northwest	Range	1.47–210.3	0.037–5.32	1.256–179.68	4.66×10^{-6}–6.7×10^{-4}	0.06–7.8	0.05–6.98
	Mean	32.05	0.81	27.38	1.02×10^{-4}	1.2	1.06
	Median	3.05	0.077	2.61	9.72×10^{-6}	0.1	0.1
Southeast	Range	5.69–195.68	0.143–4.94	4.86–167.19	1.8×10^{-5}–6.23×10^{-4}	0.2–7.3	0.19–6.49
	Mean	87.67	2.21	72.8	2.79×10^{-4}	3.3	2.91
	Median	88.15	2.22	73.2	2.8×10^{-4}	3.3	2.92
Southwest	Range	7.02–117.88	0.17–2.98	5.99–100.72	2.23×10^{-5}–3.75×10^{-4}	0.3–4.4	0.23–3.92
	Mean	30.08	0.76	25.7	9.58×10^{-5}	1.1	0.99
	Median	22.3	0.56	19.05	7.1×10^{-5}	0.8	0.74
Total	Range	0.136–2027.5	0.003–51.26	0.116–1732.4	4.3×10^{-7}–6.4×10^{-3}	0.005–75.42	0.005–67.34
	Mean	92.42	2.34	78.97	2.9×10^{-4}	3.4	2.95
	Median	22.13	0.55	18.9	7.05×10^{-5}	0.8	0.72

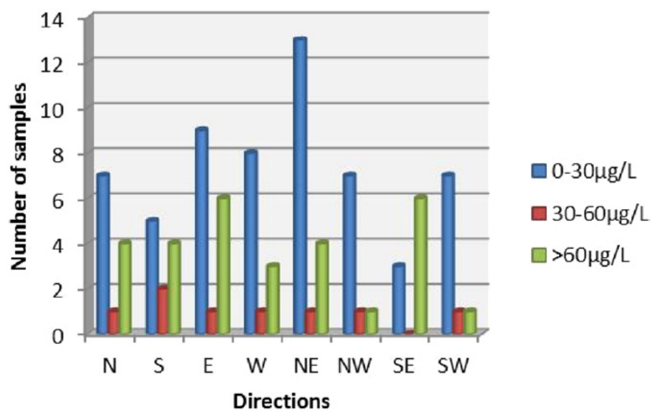

Figure 2. Bar graph showing the number of samples in the various ranges of uranium concentration in the specified directions.

4.2. Chemical risk

The risk due to chemical toxicity of uranium was estimated using equations (2) and (3). The estimated LADD is found to be in the range 0.005 to 75.42 μg kg^{-1} d^{-1} with a mean of 3.4 μg kg^{-1} d^{-1}. The reference dose ($D_{\rm Rf}$) was taken as 1.12 μg kg^{-1} based on the average intake of water as 2 L d^{-1}. Out of 96 water samples collected from the bore wells of the study area, 37 samples showed HQ values greater than 1. Looking at the chemical risk direction-wise, the results show all upper limit values to be higher than $D_{\rm Rf}$. The average value is also found to be higher than $D_{\rm Rf}$ except in southwest region of the study area. The south region of the study area shows a wide variation in the concentration of uranium and hence the value of LADD (0.2–75.42 μg kg^{-1} d^{-1}). The mean value (9.9 μg kg^{-1} d^{-1}) also varies considerably from the median (1.3 μg kg^{-1} d^{-1}) indicating that this region requires a more precise study in terms of a larger number of samples. A similar trend of variations is observed in the north and east regions also. The southeast and southwest regions show the values of mean and median equal or nearly equal. A value of HQ $>$ 1 indicates that the risk arising out of chemical toxicity of uranium as a heavy element is high.

The result obtained in the present study are compared with the report in an epidemiological study by Kurttio *et al* [18] which was used to define a no-effect group due to the ingestion of uranium. In their study, the no observed adverse effect level (NOAEL) was estimated as 1094 μg d^{-1} considering the daily intake of water as 2 L, which corresponds to a concentration of 547 μg L^{-1} of uranium. Based on that study, and taking into account the difference in intraspecies sensitivity, the WHO has set the tolerable daily intake (TDI) as 60 μg [1]. In the present study, the range of concentration of uranium in the water samples of the study area is 0.136 to 2027.5 μg L^{-1}. With a daily intake of 2 L of water of such concentration, ingestion is 0.27 to 4055 μg d^{-1} which is very high compared to the TDI set by WHO and the NOAEL reported by Kurttio *et al*.

The chemical toxicity estimated as the LADD due to the ingestion of uranium through drinking water along the specified directions of the study area and plotted as a box-and-whisker diagram is presented in figure 3.

5. Conclusion

The present investigation on the concentration of uranium in potable groundwater samples and the associated health risk assessment revealed that about 39% of the groundwater samples

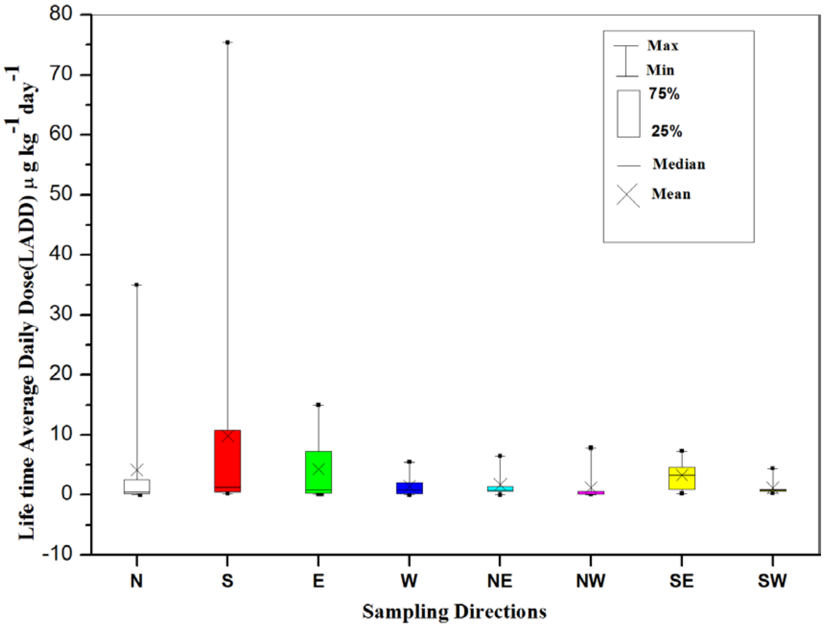

Figure 3. Box-and-whisker plot showing lifetime average daily dose (LADD) in the specified study directions.

show a concentration of uranium higher than the safe limit of $30\,\mu g\,L^{-1}$ set by WHO (2011). On comparing the radiological and chemical risks associated with the ingestion of uranium through drinking water, it was found that out of the total number of water samples (96) collected from the study area, about 6% show values higher than the acceptable level of 10^{-3} for radiological risk, whereas 39% of the samples show risk due to chemical toxicity of uranium. Hence the chemical toxicity of uranium should be of more concern than its radiological toxicity in the area that was surveyed. A more detailed analysis is suggested for the areas where relatively high values of uranium concentration were observed.

Conflict of interest

There are no conflicts of interest.

Acknowledgments

The authors express their gratitude to the residents of the study area for their cooperation during the sample collection. One of the authors (Gladys Mathews) also thanks the University Grants Commission (UGC) for granting the permission under the Faculty Development Programme (FDP) to pursue this research work.

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