Distribution of uranium and selected toxic heavy metals in drinking water of Garhwal Himalaya, India

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Abstract

This paper reports the concentrations of uranium and heavy metals in drinking water samples from Garhwal Himalaya, India determined using LED Fluorimeter and Atomic Absorption Spectroscopy (AAS), respectively. The radiological (carcinogenic) and chemical (non-carcinogenic) risks associated with the consumption of uranium in water were estimated for the public. The concentrations of natural uranium in the analyzed drinking water samples vary from 0 to 21.57 ppb with a mean value of 1.54 ppb. The average concentrations of heavy metals in the analyzed drinking water samples were found to be in the order of iron (3.99 ppm) > zinc (0.32 ppm) > copper (0.04 ppm) > nickel (0.01 ppm) > chromium and lead (Below Detection Level). The estimated risk quantities were found to be lower than World Health Organization (WHO) and United State Environmental Protection Agency (USEPA) guideline values.

Introduction

The consumption of high levels of uranium and toxic heavy metals in drinking water is a major health concern due to its chemical and radiological toxicity. The presence of certain amounts of heavy metals in drinking water like iron (Fe), copper (Cu), and zinc (Zn), etc., can be advantageous, whereas others, like chromium (Cr), lead (Pb), rare earth metals and uranium (U), etc., can be harmful to human beings. As per World Health Organization (WHO), prolonged exposure to contaminated water exposes individuals to preventable health risks. Microbial (bacterial, viral, protozoan, or other biological) contaminants cause a great majority of water-related health issues. The naturally occurring actinide elements are uranium (U), with atomic number (Z = 92), thorium (Th) (Z = 90), and artificial elements like plutonium (Z = 94) [1]. Uranium is one of the heaviest elements which is both chemically and radiologically toxic. Chemical toxicity of uranium would pose a significant threat to health than radiotoxicity through drinking water ingestion levels [2]. Despite extremely high natural uranium concentrations in drinking water in Southern Finland dug wells, no obvious clinical signs have been noticed among the exposed people [3]. Multiple investigations have shown that consumption of groundwater with more than 200 ppb for an extended period of time increases internal radiation exposure and chemical toxicity [4]. One of the most important challenges is to determine whether the radiation dose obtained from drinking water containing radionuclides is lower than that received from other sources of radiation [5]. Therefore, the presence of high levels of radioactive elements in drinking water cannot be ignored from a health risk point of view. Chronic exposure to radioactive elements through drinking water can cause a variety of health issues.

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Uranium is present in the environment as a result of leaching, mill tailings, nuclear industry emissions, coal and fuel burning, and the usage of uranium-containing phosphate fertilizers. Uranium absorption from the air is modest, while dietary consumption appears to be between 1 and 4 g day^{-1}. The majority of uranium that humans consume comes from drinking water [5, 6]. The nephrotoxic effects of uranium are caused by its chemical toxicity rather than its radiotoxicity [7]. Uranium is found in oxic (containing O_2) water with varied oxidation states in nature [1]. The hexavalent and tetravalent states of uranium are the most prevalent states. Due to the insolubility of almost all tetravalent uranium compounds (U^{4+}), the hexavalent state of uranium (U^{6+}) is particularly relevant in water. The uranyl ion $\left(UO_2^{2+}\right)$ is the hexavalent form of uranium that is typically linked with oxygen in nature [6, 8]. Water-soluble uranium compounds like uranyl nitrate ($UO_2(NO_3)_2$), fluoride, uranium hexafluoride (UF_6), and tetrachloride (UCl_4) lead to exceptionally intense systemic effects. However, moderate to low systemic toxicity effects are due to insufficiently water-soluble substances such as ammonium diuranate ($(NH_4)_2U_2O_7$) and uranium tetrafluoride (UF_4). Imperceptible systemic toxicity is due to insoluble uranium compounds such as peroxide ($UO_4 \cdot nH_2O$), trioxide (UO_3), uranium dioxide (UO_2), and triuranium octaoxide (U_3O_8) [1]. Uranium concentration above the permissible limit in drinking water can lead to adverse biological effects associated with stomach cancer, kidney damage, and urinary tract infection. Principally, it may cause severe DNA damage if it enters the nucleus of a cell. Uranium accumulates in the human body, most likely in the bones, kidneys, and liver, and is excreted through urine at a higher rate from the blood than from organ deposits [9–14].

Human exposure to dissolved hazardous substances is mostly through drinking water. The existence of hazardous heavy metals, even at trace levels in hydrological media, poses a significant hazard to human health as well as aquatic biodiversity. Iron (Fe), copper (Cu), zinc (Zn), and many other heavy metals are prescribed for metabolism in limited amounts. The impairment of the proper functioning of numerous organs and tissues can arise owing to long-term exposure to heavy metals [15]. Life-threatening diseases (cancer, mutation in the genetic material, renal failure, etc.) are potentially caused by exposure to heavy metal-contaminated water even at a modest amount [15]. Some essential metals, such as Zn and Fe, are required for human health and are regarded as non-toxic within specified limits. While others, such as chromium (Cr), copper (Cu), and arsenic (As), are considered non-essential elements due to their adverse health impacts [16, 17]. The consumption of Iron (Fe) above the safe limit causes hemochromatosis. Hemochromatosis occurs when ordinary regulatory mechanisms fail to deliver sufficient iron and assist tissue fissures as a result of iron accumulation [18]. Consumption of copper (Cu) contaminated drinking water beyond the recommended limit has been linked to infections of the intestines and stomach, vomiting, and nausea [12, 19]. Although excessive consumption of the nontoxic metal zinc (Zn) can induce liver and renal failure as well as anemia [12, 20]. Excessive use of Lead (Pb) contaminated drinking water has the potential to harm the reproductive system and kidneys. Consumption of Lead-contaminated water can also lead to neurological problems, culminating in crimson urine, brain damage, and urinary tract injury [2, 12]. The presence of chromium (Cr) in drinking water has been linked with cancers of the liver, lungs, and kidneys [14].

In Garhwal Himalaya, natural spring water is regularly used for drinking purposes by the local population. The spring waters are distributed to dwellings in rural areas through municipal supply. The significantly high values of radon concentrations in the potable groundwaters of Rudraprayag and Budhakedar of Tehri Garhwal region were reported as 3047 Bq L^{-1} and 400 Bq L^{-1} [21, 22]. Since radon is the decay product of the U-238 series, it is worthwhile to investigate the U concentration in potable groundwaters of this region for health risk assessment. In the present investigation, the drinking water samples were collected from different natural springs located in Garhwal Himalaya and were analyzed for uranium and heavy toxic metals (Cu, Fe, Zn, Pb, Ni, and Cr) concentrations. The measured values of U concentrations were used to estimate associated radiological and chemical health hazards. Assessment of associated health risks has been discussed based on the concentrations of heavy metals.

Guidelines for uranium in drinking water

The highest acceptable levels of uranium concentration in drinking water, according to the World Health Organization (WHO), the U.S. Environmental Protection Agency (USEPA), and the Atomic Energy Regulatory Board, Government of India on uranium radiotoxicity, are 30 ppb, 30 ppb, and 60 ppb, respectively [23–28]. The recommended maximum acceptable limit for heavy metals in drinking water is summarized in Table 1 [5, 29].

According to WHO and the Bureau of Indian Standards (BIS), the recommended maximum acceptable limit is 8.5 and 6.5 to 8.5 for pH and 500 mg L^{-1} and 500 mg L^{-1} for TDS of drinking water respectively [28, 29]. According to WHO, USEPA, AERB, and Health Canada, the recommended maximum acceptable value of excess cancer risk (ECR) for Uranium is 8.4×10^{-5}, 8.5×10^{-5}, 16.8×10^{-5} and 5.6×10^{-5}, respectively [23, 26, 28].

Table 1 The safe limit for ingestion of heavy metals in drinking water, recommended by WHO and BIS

|	Maximum permissible limit (ppm)					
Elements	Cu	Fe	Zn	Pb	Ni	Cr
WHO	2	NA	NA	0.01	0.02	0.05
BIS	0.05	0.3	5	0.01	0.02	0.05
BIS (in the absence of an alternate source)	1.5	NA	15	NA	NA	NA

Study area

The geological map of the study area is shown in Fig. 1. Drinking water samples were collected from Rudraprayag (30.38°N, 78.99°E to 30.65°N, 79.09°E), Tehri Garhwal (30.33°N, 78.40°E to 30.57°N, 78.79°E), and Uttarkashi (30.72°N, 78.34°E to 30.90°N, 78.68°E) regions of Garhwal Himalaya, India in December 2021.

Materials and methods

Sample collection

Water samples WERE collected in borosil glass vials (30 mL) from 87 areas. The vials were rinsed before sampling to avoid mineral contamination, and 0.1 M HNO_3 solution was added in water samples to preserve the uranium concentration in water samples. In the case of hand pumps, to avoid rusting of water pipes, the hand-pumps were run for a few minutes before water sample collection. Water samples were collected directly either from hotsprings or natural spring water. 29 samples (1 hot spring, 6 handpumps, and 22 natural spring water) were collected from Rudraprayag, 28 (7 handpumps and 21 natural spring water) from Tehri Garhwal and 30 (1 hot spring, 10 handpumps, and 19 natural spring water) from Uttarkashi. In rural areas, people mostly use natural spring water for drinking purposes, and hot spring water is widely used as a thermal spa. Samples were filtered with a filter paper such as Whatman Qualitative Filter Paper or Millipore filters to remove suspended particles as small as 2 microns before analysis.
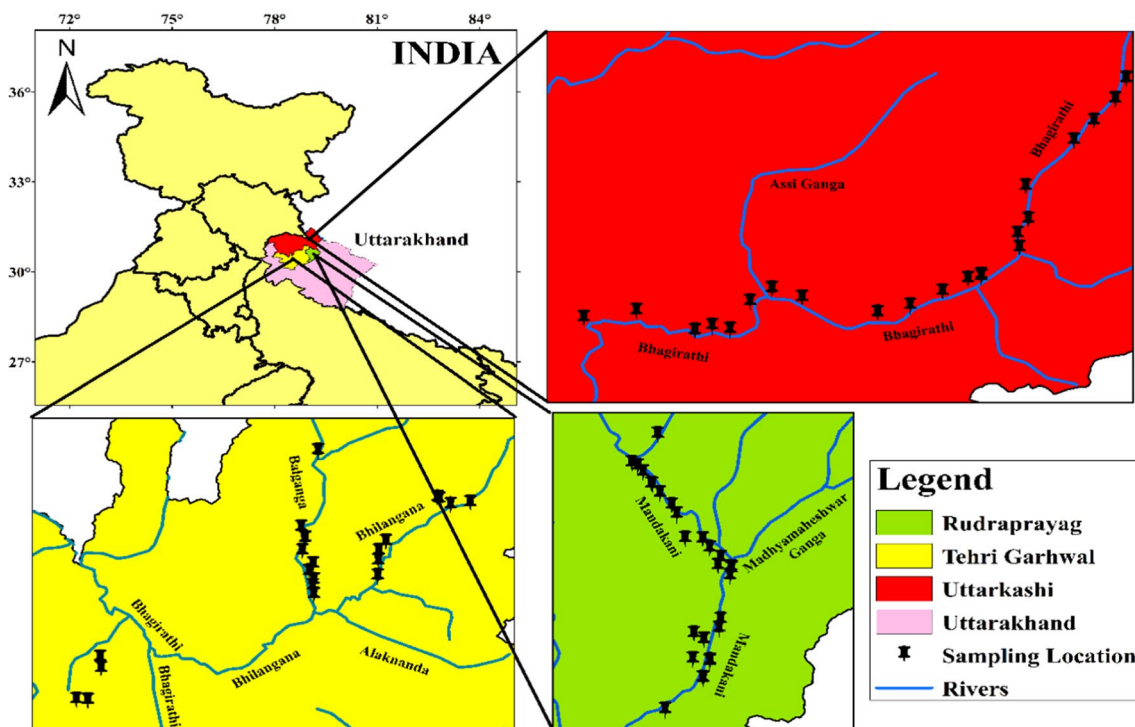
Fig. 1 Geographical map of study area showing sampling locations

Measurement of uranium and heavy metals in drinking water

The uranium content in water samples was measured using the LED fluorimeter (LF-2a Quantalase Enterprises Pvt. Ltd.). The heavy metal (Pb, Cu, Cr, Fe, Zn, and Ni) concentrations were measured using atomic absorption spectrometry (AAS) in randomly selected 41 water samples. According to the principle of the LED fluorimeter, uranium in the water sample is exposed to UV light. The uranium concentration in water samples is proportional to fluorescence generated in the visible green spectrum. The range to measure uranium concentration in LF-2a LED Fluorimeter is 0.5 ppb to 1000 ppb with an efficiency of $\pm 10\%$ or 0.05 ppb, whichever is larger, and repeatability of better than $\pm 5\%$. The instrument was calibrated with a standard solution of uranium of known concentration before analyzing the water samples. Fluorescence of 6 mL distilled water with 10% fluren (Sodium Pyrophosphate) and then the 6 mL known concentration of uranium standard with 10% fluren (Sodium Pyrophosphate) was used for the calibration of the instrument. A cuvette rinsed with distilled water was filled with 6 mL of sample water and 10% (0.6 mL) buffer solution/fluren (Sodium Pyrophosphate). The buffer solution increases the fluorescence yield by one or more orders of magnitude [14, 30]. The concentration of heavy metals in water samples was measured using Atomic Absorption Spectrometry (AAS, model no. AA7000 Shimadzu Corporation). The detailed information of the instrument is explained elsewhere [31].

Physicochemical characteristics of water samples

Physicochemical parameters were measured in collected water samples using a specific device such as pH using a pH meter, electrical conductivity (EC) using a conductivity meter, and total dissolved solids (TDS) using a TDS meter. Assessment of physicochemical properties (pH, EC, and TDS) gives crucial in-situ information regarding the drinking water's quality.

Radiological risk assessment

The radiological risk, or carcinogenic risk, associated with uranium exposure through drinking water is measured in lifetime ECR and calculated as follows [14, 26, 32, 33]:

$$Excess\ Cancer\ Risk = \left(A_U\right) \times R \tag{1}$$

where the activity of uranium (in Bq L^{-1}) is represented for 'A_U' and the risk factor stands for 'R'. The risk factor (R) is derived using the following equation:

$$Riskfactor(R) = r \times I \tag{2}$$

where in this equation cancer risk constant of U (1.19×10^{-9}) for mortality represented by r and per capita activity intake of uranium for I. 'I' is defined as the product of a human's average life span (23,250 days) [34] and the rate of water consumption (IR) (2 L d.$^{-1}$) [5, 35].

$$I = IR \times 23250\ days \tag{3}$$

Chemical risk assessment

The lifetime average daily dose (LADD) is defined as the amount of uranium consumed per kilogram of body weight every day. The lifetime average daily dose (LADD) is represented for chemical (non-carcinogenic) risk of uranium exposure and determined using the following equation [36–38]:

$$LADD\left(\mu g Kg^{-1} day^{-1}\right) = \frac{C_U \times IR \times EF}{BW \times 365} \tag{4}$$

where concentration of Uranium or metals (ppb) represents C_U, BW: receptor's typical body weight (70 kg), EF: exposure frequency (365 days year^{-1}), and IR: water intake rate (2 L d^{-1}).

Hazard quotient

The hazard quotient is defined as the estimated health hazard due to the consumption of uranium-contaminated drinking water. It is derived from the following expression:

$$HQ = \frac{LADD}{R_f D} \tag{5}$$

where, LADD is cited in Eq. 4 and the reference dose stands for $R_f D$ [27, 39]. The daily dose that an exposed person can endure with the amount of exposure for an extended period without experiencing any adverse effects is used to define the reference dose [5, 26, 40]. The $R_f D$ (3 µg kg^{-1} day^{-1}) recommended by WHO and USEPA was considered to calculate the hazard quotient in the present study [5, 26].

Age-dependent ingestion dose estimation

The radiation doses from drinking water contaminated with uranium for individuals of various ages were calculated using International Atomic Energy Agency (IAEA) dose conversion coefficients and projected water consumption rates [39, 41, 42].

$$Annual\ Ingestion\ Dose = A_u \times I_A \times 365 \times F \tag{6}$$

where uranium activity in water (Bq L^{-1}) denotes A_u the dose conversion factor (4.5×10^{-8} Sv Bq^{-1}) for U refers to F and daily water intake for different age groups denotes I_A.

The mass concentration (ppb) of uranium was multiplied by a factor 25.2 to convert it into activity concentration (mBq L^{-1}) [43].

Results and discussion

Physiochemical analysis

Table 2 shows the statistical values for the measured physicochemical properties of water samples. The pH of all water samples was found within the WHO and BIS suggested maximum allowable level (8.5) [5, 29]. The pH of hot spring water from Rudraprayag and one natural spring water sample from Uttarkashi was found to be below the lower limit (6.5) of the permitted value suggested by the BIS. The intake of drinking water with a pH of 6.5 prohibits the body from producing vitamins and minerals [44]. The measured TDS values in 8 samples of Rudraprayag, 8 samples of Tehri Garhwal, and 9 samples of Uttarkashi were less than the WHO and Bureau of Indian Standards allowed limits [5, 29]. TDS levels in Rudraprayag, Tehri Garhwal, and Uttarkashi were found to be higher above the WHO and BIS permitted range in 21 samples, 20 samples, and 21 samples, respectively. TDS levels beyond a certain threshold might have negative health consequences, such as paralysis of the tongue, lips, and face [44]. The electrical conductivity of water is used to determine the cleanliness of the water. It is determined by the existence of ions, their concentrations, mobilities, and relative concentrations, among other factors. Figure 2 illustrates frequency distribution curves for pH, TDS, EC, and Salinity of 87 drinking water samples taken from 87 investigated locations. Rudraprayag, Tehri Garhwal, and Uttarkashi each had 8 samples, 17 samples, and 8 samples with acidic character (pH < 7), respectively, whereas 13 samples, 8 samples, and 19 samples with alkaline character (pH > 7), respectively. However, 8 samples from Rudraprayag, 3 from Tehri Garhwal, and 3 from Uttarkashi were found to have a neutral nature (pH = 7).

The pH of 56% of water samples from the investigated sites ranged from 7 to 7.3, 6% percent from 7.4 to 7.7, 4% from 6.2 to 6.5, and 34% percent from 6.6 to 6.9 as shown in Fig. 2a. As shown in Fig. 2b, TDS values varied in range from 600 to 800 mg L^{-1} in 44% drinking water samples, whereas 53% of the samples were below this range and 3% above. The majority of samples (39%) showed EC in the range of 900 to 1100 μS cm^{-1} (Fig. 2c). The remaining 53% of samples were less than 900 μS cm^{-1}, and only 8% were greater than 1100 μS cm^{-1}. The salinity of the majority of the samples (60 percent) was in the range of 0.3 to 0.4 (Fig. 2d). Salinity levels were above and below this range in 19% and 21% of the total samples, respectively.

Uranium concentration in drinking water

Table 3 summarizes the statistical characteristics of uranium concentrations in water samples evaluated with an LED fluorimeter. The uranium concentrations in the examined sample of the investigated area were lower than the allowed level recommended by WHO, USEPA, and AERB (Department of Atomic Energy, Government of India as a limit for uranium in drinking water on radiotoxicity) [5, 23, 40]. The committed dose due to total natural uranium ranges from 0.001 to 5.07 with an average value of 0.60 in terms of (μSv y^{-1}) in Rudraprayag, 0.001 to 6.23 with an average value of 0.75 in terms of (μSv y^{-1}) in Tehri Garhwal and 0.01 to 18.14 with an average value of 2.41 in terms of (μSv y^{-1}) in Uttarkashi. The table shows the estimated values of radiological and chemical risk quantities. The projected value of ECR is below the WHO, USEPA, AERB, and Health Canada safe levels. The HQ values of Rudraprayag, Tehri Garhwal, and Uttarkashi samples were less than 1, indicating that there is no detrimental health effect associated with uranium toxicity in water. Figure 3 indicates that uranium concentrations are less than 2 ppb in the majority of collected drinking water samples (80%). While 20% of the total number of samples have uranium concentrations ranging from 2 to 25 ppb.

Only one sample from the Uttarkashi area showed the highest uranium concentration of 21.57 ppb, which was still less than the recommended safe limit of 30 ppb [27]. The concentration of natural uranium in drinking water varied from 0 to 21.57 ppb with an average of 1.53 ppb in Garhwal Himalaya. As depicted in Table 4, the age-dependent ingestion dose estimation owing to consumption of uranium-contaminated drinking water was represented statistically. The

Table 2 Statistical parameters for measured physicochemical characteristics of water samples

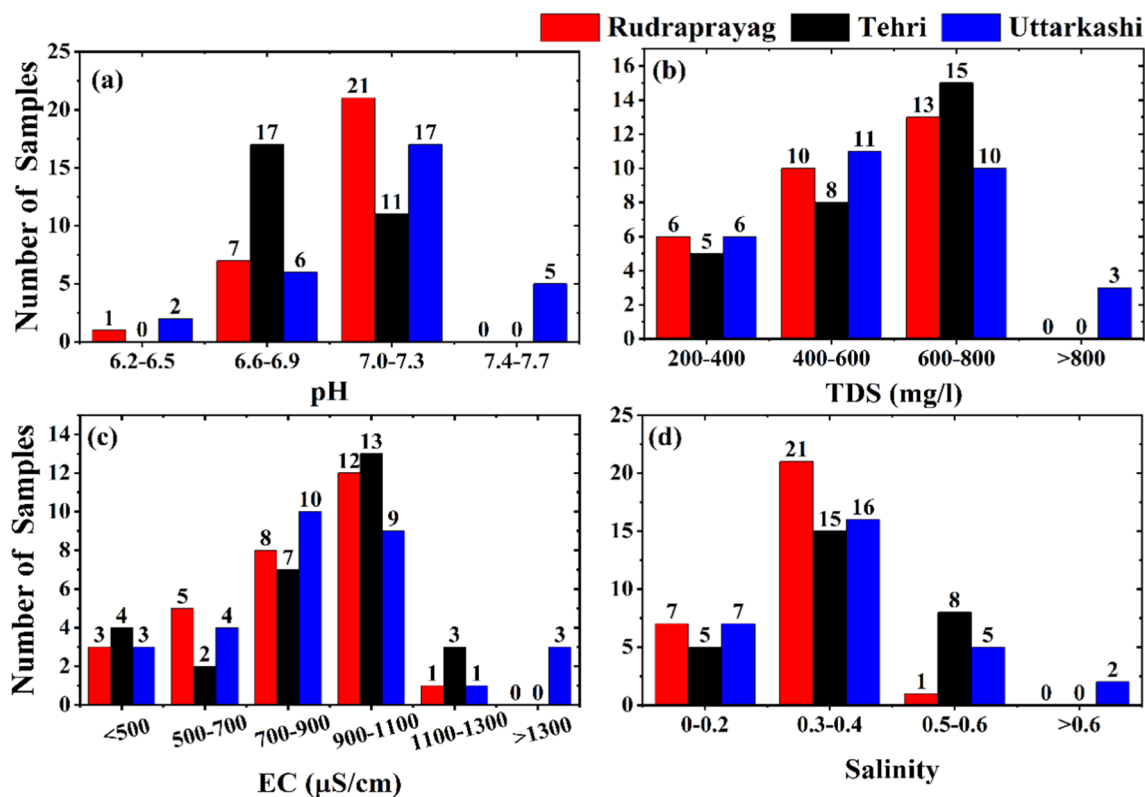|	Rudraprayag					Tehri Garhwal					Uttarkashi				
	Avg	Min	Max	SD	GM	Avg	Min	Max	SD	GM	Avg	Min	Max	SD	GM
pH	7.0	6.4	7.3	0.2	7.0	7.0	6.7	7.3	0.2	7.0	7.1	6.3	7.4	0.3	7.1
TDS (mg L^{-1})	550.9	264.0	742.0	136.2	531.2	578.1	273.0	790.0	151.9	555.1	807.2	262.0	6860.0	1174.0	605.5
EC (μS cm^{-1})	822.2	394.0	1106.0	203.5	792.8	859.0	406.0	1152.0	221.4	825.7	1201.1	389.0	10,220.0	1750.1	898.5
SAL	0.3	0.1	0.5	0.1	0.3	0.4	0.1	0.5	0.1	0.3	0.6	0.1	5.7	1.0	0.4

Fig. 2 The frequency distribution of **a** pH, **b** TDS, **c** EC, and **d** salinity in 87 drinking water sources

Table 3 Statistical metrics for observed uranium content and associated health risk in the analyzed water samples

	Rudraprayag					Tehri Garhwal					Uttarkashi				
	Avg	Min	Max	SD	GM	Avg	Min	Max	SD	GM	Avg	Min	Max	SD	GM
U (ppb)	0.71	0.001	6.03	1.39	0.20	0.89	0.001	7.41	1.92	0.21	2.86	0.01	21.57	5.44	0.50
U (mBq L^{-1})	17.87	0.04	151.93	35.02	5.06	22.45	0.04	186.65	48.30	5.17	72.15	0.22	543.59	137.17	12.50
LADD ($\times 10^{-3}$ µg kg^{-1} d^{-1})	20.26	0.05	172.25	39.70	5.73	25.45	0.05	211.62	54.76	5.86	81.80	0.25	616.32	155.52	14.17
ECR (in 10^{-7})	9.89	0.02	84.07	19.38	2.80	12.42	0.02	103.28	26.72	2.86	39.92	0.12	300.80	75.90	6.92
HQ (in 10^{-2})	0.68	0.00	5.74	1.32	0.19	0.85	0.00	7.05	1.83	0.20	2.73	0.01	20.54	5.18	0.47

calculated annual ingestion dose rates for persons of various age groups were observed to be less than the WHO standard value of 100 µSv y^{-1} [5]. Because of the difference in water intake rate, the dose rate of ingestion of heavy metals contaminated drinking water for 0—6 old month infants is below that for 7—12 old month infants, as shown in Table 4. Furthermore, the estimated ingestion dose for infants and children is lower than that for adults. As compared to adults, the tissues of babies and children may be more vulnerable to radiation resulting from the consumption of contaminated water from uranium exposure. Increased heavy metals contaminated water consumption is responsible for the

higher ingestion dose given to females during lactation and pregnancy.

Analysis of heavy metals

Table 5 shows the concentration of several heavy metals in examined water samples. The quantities of heavy metals in drinking water in Rudraprayag, Tehri Garhwal, and Uttarkashi were found to be within WHO and BIS recommended safe levels [5, 29], with the exception of iron, which was found to be higher than the guideline value. The concentrations of Fe, Zn, Cu and Ni were found to vary from 0.18
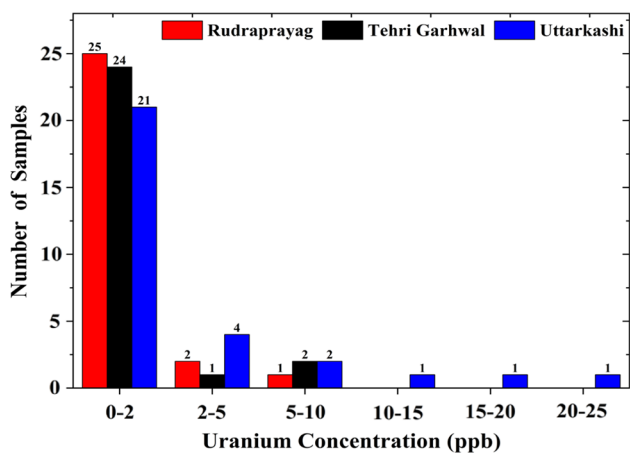
Fig. 3 Frequency distribution of uranium content in drinking water samples collected from different regions of Garhwal Himalaya, India

to 38.51 ppm with an average of 3.99 ppm, 0.02 to 4.08 ppm with an average of 0.32 ppm, 0.001 to 0.30 ppm with an average of 0.04 ppm and 0.002 to 0.02 ppm with an average of 0.01 ppm, respectively. Howeever, the concentrations of Cr and Pb were observed below detection level (BDL).

The HQ value was determined to be less than 1, indicating that the chemical toxicity of heavy metals in water has no

detrimental health effects stated in Table 6. As a result, it can be stated that drinking water in the researched location poses no danger owing to the chemical toxicity of heavy metals.

Conclusions

The results of this investigation concluded that uranium concentrations in drinking water in most of the locations in the study area are substantially below the World Health Organization's recommended limit of 30 ppb. The uranium content in groundwater may be important in the geochemical exploration of uranium and understanding geochemical processes in Himalayan areas, in addition to assessing health risks. The concentrations of Pb, Fe, Cu, Cr, Ni, and Zn in drinking water samples are considerably below the corresponding WHO and BIS safe standards. The predicted values of age-dependent ingestion doses reveal that uranium exposure by drinking water has no major health risk. The estimated annual ingestion dose rates for persons of various age groups were observed to be less than the WHO standard value.

Table 4 Statistical parameters of estimated annual ingestion dose (in multiples of 10^{-5} Sv year^{-1}) for various age groups from exposure to uranium in drinking water

	Infants	Children			Males			Females			Pregnancy	Lactation
	0–6 m	7–12 m	1–3 year	4–8 Year	9–13 Year	14–18 year	Adults	9–13 year	14–18 year	Adults	14–50 year	14–50 year
Rudraprayag												
Avg	0.021	0.023	0.038	0.050	0.070	0.097	0.109	0.062	0.068	0.079	0.088	0.112
Min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max	0.175	0.200	0.324	0.424	0.599	0.823	0.923	0.524	0.574	0.674	0.749	0.948
SD	0.040	0.046	0.075	0.098	0.138	0.190	0.213	0.121	0.132	0.155	0.173	0.219
GM	0.006	0.007	0.011	0.014	0.020	0.027	0.031	0.017	0.019	0.022	0.025	0.032
Tehri Garhwal												
Avg	0.026	0.029	0.048	0.063	0.088	0.122	0.136	0.077	0.085	0.100	0.111	0.140
Min	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Max	0.215	0.245	0.399	0.521	0.736	1.012	1.134	0.644	0.705	0.828	0.920	1.165
SD	0.056	0.063	0.103	0.135	0.190	0.262	0.294	0.167	0.182	0.214	0.238	0.301
GM	0.006	0.007	0.011	0.014	0.020	0.028	0.031	0.018	0.020	0.023	0.025	0.032
Uttarkashi												
Avg	0.083	0.095	0.154	0.201	0.284	0.391	0.438	0.249	0.273	0.320	0.356	0.450
Min	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Max	0.625	0.714	1.161	1.518	2.143	2.946	3.304	1.875	2.054	2.411	2.679	3.393
SD	0.158	0.180	0.293	0.383	0.541	0.743	0.834	0.473	0.518	0.608	0.676	0.856
GM	0.014	0.016	0.027	0.035	0.049	0.068	0.076	0.043	0.047	0.055	0.062	0.078

Table 5 Statistical parameters of heavy metal concentrations in drinking water samples of Garhwal Himalaya, India

Elements (in ppm)	Rudraprayag					Tehri Garhwal					Uttarkashi				
	Avg	Min	Max	SD	GM	Avg	Min	Max	SD	GM	Avg	Min	Max	SD	GM
Cr	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Ni	0.009	BDL	0.021	0.014	0.009	0.013	BDL	0.014	0.010	0.013	0.006	BDL	0.019	0.009	0.004
Pd	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Zn	0.519	BDL	4.083	1.072	0.155	0.126	BDL	0.483	0.117	0.100	0.365	0.021	1.517	0.549	0.145
Fe	4.580	0.180	38.514	9.933	1.727	2.936	1.129	16.396	3.946	2.080	4.502	1.770	19.834	5.447	3.078
Cu	0.070	BDL	0.303	0.083	0.041	0.028	BDL	0.052	0.023	0.016	0.023	BDL	0.074	0.026	0.014

Table 6 Statistical parameters of estimated health risks due to uranium concentration in drinking water of Garhwal Himalaya, India

Elements	$R_f D$	Rudraprayag		Tehri Garhwal		Uttarkhasi	
		LADD ($\times 10^{-2}$ mg kg^{-1} d^{-1})	HQ (in 10^{-2})	LADD ($\times 10^{-2}$ mg kg^{-1} d^{-1})	HQ (in 10^{-2})	LADD ($\times 10^{-2}$ mg kg^{-1} d^{-1})	HQ (in 10^{-2})
Cr	1.500	BDL	BDL	BDL	BDL	BDL	BDL
Ni	0.020	0.03	1.30	0.04	1.82	0.01	0.62
Pd	0.004	BDL	BDL	BDL	BDL	BDL	BDL
Zn	0.300	0.44	1.47	0.29	0.95	0.41	1.38
Fe	0.700	4.93	7.05	5.94	8.49	8.79	12.56
Cu	0.040	0.12	2.95	0.05	1.14	0.04	0.99

Declarations

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