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Assessment of Radiological Risks and Chemical Toxicity due to Exposure of Uranium in Water Samples of District Mahendergarh Haryana, India

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In this study, we focused on assessing the concentration of uranium in drinking water samples from 50 locations in the Mahendergarh district of Haryana state, India, using a LED Fluorimeter Quantalase (LF-2a). Uranium, a radioactive element, can pose risks to human healthif ingested excessively over long periods. Our observations revealed significant variation in uranium concentration in water samples, with a mean value of 10.8±1 μg l^{-1}. However, it is worth noting that this value fallswithin the recommended safe limit for drinking water. Additionally, we conducted calculations to estimate the annual uranium ingestion dose, which ranged from 0.11 μSv y^{-1} to 43.8 μSv y^{-1}. The maximum annual ingestion dose is calculated for the adult male group. The lifetime average daily dose of uranium was also calculated, value was found to vary from 0.01 μg kg^{-1} day^{-1} to 0.81 μg kg^{-1} day^{-1}, with an average value of 0.31 μg kg^{-1} day^{-1}. We also identified a weak positive correlation between groundwater depthand uranium concentration.

Keywords: LED fluorimeter; Uranium; Radiological risk assessment; Chemical risk analysis; Radioactivity

1 Introduction

Lack of environmental control has turned drinking water into a major issue globally. Various sources like rivers, ponds, groundwater, and submersibles are the primary sources of water. Unfortunately, groundwater often gets contaminated by harmful substances[1]. People are exposed to ionizing radiation from cosmic rays and natural atmospheric radiations. These radiations are present in all groundwater samples, and their varying concentration depending on the geological and geographical structure of groundwater origin[2].

Uranium is a naturally occurring radioactive element found in air, water, soil, and locally food grown. It is one of the heaviest elements with low specific activity and extensive decay time[3,4]. There are three isotopes of Uranium ^{238}U, ^{235}U, and ^{234}U and they make up 99.3%, 0.7%, and 0.005% of the environment, respectively. Interestingly, all these isotopes have similar chemical properties such as boiling point, melting point, and volatility, but differ in radiological properties (decay mode, long half-life, and specific activity). Uranium has been detected in bedrock[5], coaly rocks, black shales, sediment rocks, granites, and metamorphic rocks, that receive their carbon influx from algae[6-10]. Unfortunately, human activities such as milling, mining, and use of fertilizers have led to elevated uranium level in groundwater[11]. In fact, the excessive use of fertilizers over the past few decades has led to the contamination of water[12,13].

Drinking water contamination poses both chemically and radiologically harmful effects to human health. Uranium (^{238}U) toxicity can damage the renal tubular epithelium and kidneys if the exposure to soluble uranium exceeds 0.1 mg per kg of body weight[14,15]. Although uranium itself is not necessarily hazardous but its decay product, radium (^{226}Rn), can be a threat. When radium is inhaled, it can cause cancers of digestive system[16], nephritis, and genotoxicity[17]. Radium concentration depends on various factors like age, sex, weight, and absorption in digestive system. Absorption coefficient for adult is 0.2 and for infant value is 1[18].Several studies in various Indian states have exposed harmful substances such as fluoride, salinity, and heavy metals

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in groundwater. A recent survey aimed to map the uranium content in drinking water sources across India. Various organizations have been monitoring uranium levels in regions such as western Haryana, northern Rajasthan, Uttarakhand, and Punjab[15,19,20,21]. High uranium level have been reported in certain regions of Punjab and Haryana, due to geogenic mobilization, granites, and volcanic rocks in these areas. Similar occurrences have been observed in various countries such as Turkey, Germany, China, Kosovo, USA, and Ghana[22-27]. These situations are often linked to marine contamination[28,29], widespread use of fertilizers in agriculture as well as the presence of volcanic and heat-producing granite rocks[30]. Numerous international agencies reviewed uranium toxicity and published results on the toxicity of uranium[4,31,32,33]. Many researchers have observed the prospect of uranium through water analysis[34]. The Ministry of Health, Haryana, confirmed 4,592 cancer related death in Haryana state in 2017. According to the National Cancer Registry Program Report of 2020, nearly 16000 people succumbed to lung cancer in males and breast cancer in cervical tracts in females in Haryana state.

This manuscript, reports that submersibles are the primary source of drinking water in surveyed area, typically found at significant depths. The Krishnavati and Dohan rivers have completely dried up due to low rainfall, hindering groundwater recharge. Consequently, dropping water level expose groundwater to rock minerals, potentially causing hazardous health issues. Therefore, a comprehensive risk assessment of uranium in the groundwater of district Mahendergarh is imperative.

2 Study Area

The studied area lies between a latitude of 27˚47' to 28˚26' N and a longitude of 75˚56' to 76˚51'E. It is bounded by Rewari to east, to the north by Charkhi Dadri Bhiwani, and to the south by the Alwar district of Rajasthan. To the west, it shares its border with the Sikar district of Rajasthan. Geologically this region is surrounded by the Aravalli Mountain range running approximately 670 km on the southwest side and contains rocks made up of granites, quartzites, and gneisses. The district also has an orogenic belt and elevated hills, including Dhosi Hill, an extinct volcano that provides a distinctive conical view from its peak, as shown in Fig. 1. Withan annual rainfall of 500 mm and predominantly arid and alluvial soil, the area faces a significant water scarcity issue. The Dohan and Krishnavati Rivers, originating from the western slope of the Aravalli hills in the Sikar and Alwar districts of Rajasthan, traverse into the Rewari district of Haryana and after an extensive journey, eventually disappear in the Mahendergarh district. This ongoing water crisis has led to the cultivation of low-water-consumption crops like mustard, guar, and pearl millet are grown in the area. Notably, the Khetri copper belt mining area in the state of Rajasthan, situated 47 km from the survey area[35], may have potential implications on the study area, leading to drinking water contamination.

3 Materials and Method

3.1 Water sampling procedure

In the Mahendergarh district, Haryana, India, 50 water samples were collected from various locations including submersibles and ponds. We recorded the latitudes and longitudes using a global positioning system (GPS), as shown in Table 1.

Prior to collecting water samples, ensured that fresh water was obtained by running the water run for approximately 10 minutes. Nitric acid (HNO_3) is used to acidify water. To eliminate sediments and impurities such as algae, we employed 0.45 micron-sized Whatman 42 filter pape. Subsequently, filtered water was stored in pre-cleaned polyethylene containers for further analysis. Sampling was executed carefully following the experimental procedure[3,15,36,37].

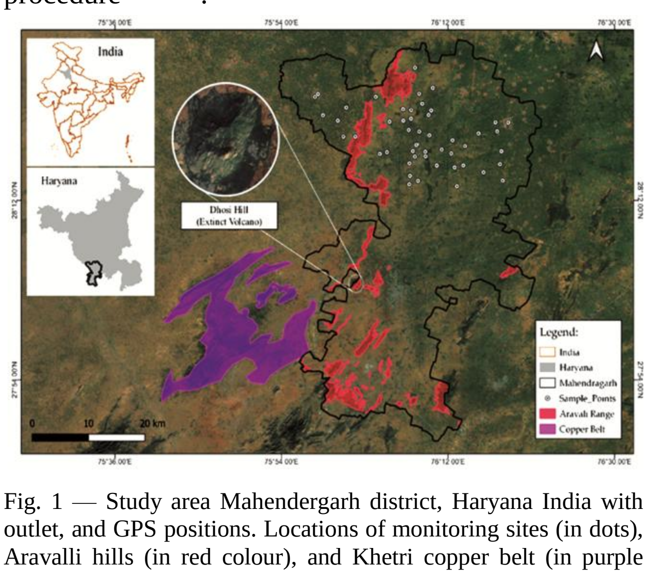

Fig. 1 — Study area Mahendergarh district, Haryana India with outlet, and GPS positions. Locations of monitoring sites (in dots), Aravalli hills (in red colour), and Khetri copper belt (in purple colour) to examine the uranium concentration in groundwater. Figure was prepared using QGIS software. (*The map is only intended to be used as a visual aid and do not indicate any view on the legal position of any country or territory or the delimitation frontiers or boundaries.)

Table 1 — The values of different parameters in drinking water of district Mahendergarh Haryana, India.

Sample code	Location	Depth (Feet)	Coordinates
H-1*	Jant	450	28˚21′42″N,76˚09′13"E
H-2**	Malra	7	28˚21′02″N,76˚10′11″E
H-3*	Malra	450	28˚20′35″N,76˚09′54″E
H-4*	Bhagdana	450	28˚18′54″N,76˚08′53″E
H-5*	Majrakalan	450	28˚18′32″N,76˚09′59″E
H-6*	Majrakhurd	400	28˚16′53″N,76˚09′32″E
H-7*	Sigri	350	28˚16′25″N,76˚09′34″E
H-8*	Sigra	350	28˚17′6″N,76˚11′19″E
H-9*	Anawas	400	28˚16′31″N,76˚12′21″E
H-10*	Jhagroli	380	28˚18′2″N,76˚12′29″E
H-11*	Buchawas	375	28˚17′27″N,76˚13′50″E
H-12*	Gudha	380	28˚18′43″N,76˚15′18″E
H-13*	Unhani	400	28˚19′50″N,76˚17′07″E
H-14*	Kanina	385	28˚19′49″N,76˚18′31"E
H-15*	Chelawas	450	28˚18′56″N,76˚17′18″E
H-16*	Ishrana	450	28˚16′56″N,76˚17′46″E
H-17*	Partal	410	28˚15′38″N,76˚17′37″E
H-18*	Bhojawas	400	28˚13′59″N,76˚17′55″E
H-19*	Sundrah	425	28˚14′49″N,76˚15′50″E
H-20*	Bawania	400	28˚15′31″N,76˚13′39″E
H-21*	Khera	400	28˚15′19″N,76˚12′43″E
H-22*	Surjanwas	350	28˚13′25″N,76˚12′58″E
H-23*	Dulana	410	28˚15′30″N,76˚10′47"E
H-24*	Mahendergarh	450	28˚16′24″N,76˚08′25″E
H-25*	Jonawas	425	28˚13′37″N,76˚07′49″E
H-26*	BhandorUeechi	400	28˚13′58″N,76˚08′45″E
H-27*	Jatwas	450	28˚14′28″N,76˚07′53″E
H-28*	Jhhankhadi	480	28˚20′N,76˚7′10"E
H-29*	Mandola	500	28˚19′54″N,76˚05′41″E
H-30*	Nangel mala	525	28˚22′23″N,76˚04′11″E
H-31*	Digrota	500	28˚21′19″N,76˚01′00″E
H-32*	Barda	510	28˚19′60″N,76˚00′05″E
H-33*	Surheti	525	28˚20′33″N,75˚58′29″E
H-34*	Satnali	510	28˚22′23″N,75˚57′37″E
H-35**	Satnali	25	28˚22′40″N,75˚57′57″E
H-36*	Dalanwas	500	28˚18′24″N,76˚00′41″E
H-37*	Madhogarh	480	28˚18′24″N,76˚01′59″E
H-38*	Rajawas	450	28˚16′40″N,76˚04′38″E
H-39*	Khatodara	490	28˚16′50″N,76˚05′24″E
H-40*	Khaira	425	28˚15′43″N76˚07′50″E
H-41*	Rewasa	400	28˚16′57″N,76˚08′12″E
H-42**	SisothDhani	20	28˚17′37″N,76˚08′41″E
H-43*	Sisoth	425	28˚17′33″N,76˚08′34″E
H-44*	Palripanihara	450	28˚19′04″N,76˚07′45″E
H-45**	Palli	30	28˚20′12″N,76˚08′00″E
H-46*	Palli	375	28˚21′09″N,76˚07′08"E
H-47*	Akoda	250	28˚25′19″N,76˚08′26″E
H-48*	Kharkara	300	28˚23′17″N,76˚10′21″E
H-49*	Bhurjat	350	28˚22′42″N,76˚08′53″E
H-50*	CUH (Central Univ. Of Haryana)	450	28˚21′04″N,76˚08′01″E

*Submersible water; **Pond water

3.2 Experimental techniques

At J. C. Bose University of Science and Technology in Faridabad(Haryana) India, an analysis of uranium in water samples was conducted using a LED Fluorimeter in the Environmental Science Research laboratory. The instrument limit of detection(LOD) for uranium in water ranges from 0.5 µg $l^{-1}$to 1000 µg l^{-1}respectively[15]. To prepare a sodium pyrophosphate solution ($Na_4P_2O_7$), mix 5 g of sodium phosphate with 100 ml of double distilled water. To achieve a reagent pH of 7, orthophosphoric acid (H_3PO_4) was added drop by drop[36,37]. For fluorescence analysis, a water sample of approximately 5 ml was mixed with 0.5 ml of a 5% sodium pyrophosphate solution in a cuvette[36]. We performed analysis five times for each sample and then calculated average. For counts of blank sample, double distilled water was used as a reference[13,37]. The minimum detection limit (MDL) of the instrument is 0.2 µg l^{-1}, accurate methods used for quality assurance and control[38]. IAEA standard reference material was used for quality control. Uranium concentration in water sample was calculated by usingequation 1

$$U\left(\frac{\mu g}{l}\right) = \frac{D_1}{D_1 - D_2} \times \frac{V_1}{V_2} C \qquad \text{... (1)}$$

Where D_1 is the sample fluorescence, D_2 is the fluorescence due to uranium spike and also due to sample, V_1 is the volume of standard used, V_2 is the sample volume, and C is the concentration of uranium standard solution.

3.2.1 Uranium concentration

To determine the concentration of uranium in groundwater, we employed LED fluorimeter Quantalase (LF-2a). This device function by exciting uranyl ions (UO_2^{2+}) in the groundwater with LED light and quantifying the resulting fluorescence through a photomultiplier tube (PMT). This provides valuable information about the presence of uranium in the groundwater as shown in Fig. 2. The activity concentration was determined utilizing a standard equation[19,21].

$$\mathit{Activity\ concentration}\ (\mathrm{Bq\ l} - 1) = \mathit{uranium\ concentration} \times 0.02528 \qquad \text{... (2)}$$

Where 1µg l^{-1} = 0.02528 Bq l^{-1}

3.2.2 Radiological risk analysis

It is defined as the lifetime cancer risk (LCR) and calculated by[15,39]using equations (3) and (4)

$$\text{Lifetime cancer risk (LCR)} = uranium\ activity(A_u) \times risk\ factor(R) \quad ...(3)$$

The risk factor was measured by multiplication of the coefficient of lifetime cancer risk (r) and I is the water ingestion for a lifetime period (70×365×2) where 70 is life expectancy age (USEPA 2011)[40], and water consumption per day = 2 l day^{-1} (WHO 2004) and constant cancer mortality of uranium, r = 1.13 $\times 10^{-9}$Bq l^{-1} (USEPA 2000)[41] and cancer morbidity constant for U, r = 1.73 $\times 10^{-9}$Bq l^{-1} (USEPA 1999).

$$\text{Where,} R = r \times I \quad ...(4)$$

3.2.3 Chemical risk assessment (LADD in µg/kg/day)

It is measured by using[42] the following standard equation (5)

$$LADD(\mu g kg^{-1} day^{-1}) = \frac{C_i \times IR \times EF \times ED}{BW \times AT} \quad ...(5)$$

Where C_i is uranium concentration (µgl^{-1}), IR is the daily intake of water (2 l day^{-1}) (USEPA 1991), EF is exposure frequency (365 days), BW is the body weight (70 kg for a man) (USEPA 1991), AT denotes average time (25550 days), and ED represents total exposure time (70 years).

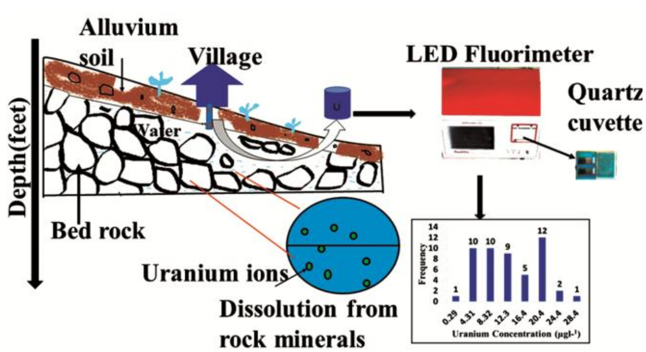

Fig. 2 — Graphical presentation of Uranium concentration in water of monitoring sites.

3.2.4 Hazard quotient (HQ)

It is the risk that comes from consuming or ingesting uranium through drinking water. If its value is below one, *i.e.*, HQ < 1 (AERB 2004), then one can say that the water quality is good; otherwise, it is not safe for drinking. It is calculated by following standard equation (6)

$$HQ = \frac{LADD}{R_f D} \quad ...(6)$$

A reference dose is defined as a dose for an individual that allows tolerating an individual for exposure to uranium without any harmful effects. Where RfD reference dose = 0.6 (µg kg^{-1} day^{-1})[43]

3.2.5 Age-dependent Annual effective dose (AED in µSv yr^{-1})

It is measured by[15,44] taking the standard following equation (7)

$$AED\ (\mu Sv/year) = A_c \times F \times I \times 365 \quad ...(7)$$

According to WHO, 2004 annual effective dose limit is 100 µSv y^{-1}

Where I indicate the daily intake of drinking water

A_c (Bq l^{-1}) is activity concentration, F is an effective dose conversion factor having a constant value (4.5 × 10^{-8} µSv yr^{-1}/Bq l^{-1} for U)

4 Results and Discussion

Using LED fluorimetry (LF-2a Quantalase), to assess the uranium concentration in 50 water samples collected from diverse locations in Mahendergarh, Haryana, India. As illustrated in Table 2, the uranium concentration in water samples ranged from (0.3±0.02) to (28.4±0.13) µg l^{-1} , with an average of (10.8±7) µg l^{-1}. Notably, the average uranium concentration was found to be below the recommended limit of 30 µg $l^{-1}$by WHO 2011, USEPA 2011, and 60 µg l^{-1} by AERB 2004.

Table 2 — Statistical parameters of Uranium concentration, activity concentration, LADD, Annual effective dose and HQ.

Statistical Parameters	Uranium conc. (µgl^{-1})	Activity conc. (Bql^{-1})	LADD (µgkg^{-1}day^{-1})	Annual Effective dose (µSvy^{-1})	HQ	Excess cancer risk (mortality)	Excess cancer risk (morbidity)
Minimum	0.3±0.02	0.007±0.0006	0.01	0.33	0.02	6.0E-06	7.0E-06
Maximum	28.4±0.13	0.72±0.005	0.81	23.65	1.35	4.2E-05	2.5E-05
Mean	10.8±1*	0.27±0.01	0.31	8.95	0.52	1.5E-05	6.4E-05
Standard Deviation	7.19	0.18	0.21	5.96	0.34	1.1E-05	1.6E-05
Standard Error	1.02	0.02	0.03	0.84	0.05	1.5E-06	2.4E-06
First Quartile	4.49	0.11	0.13	3.61	0.22	–	–
Median Quartile	9.82	0.24	0.28	8.05	0.47	–	–
Third Quartile	17.01	0.43	0.49	14.04	0.82	–	–
Skewness	0.37	0.36	0.37	0.36	0.37	–	–
Kurtosis	-0.89	-0.89	-0.90	-0.89	-0.90		

*Uncertainty is given within 1 standard deviation

The presence of uranium in drinking water samples in the area may be attributed to various factors, including the physiochemical parameters[29], geological influences of Aravalli hills, mining, urbanization in Gurugram, and rapid industrialization in Rewari and Jhajjar (according to a report by India Today in 2018). Copper mining in Rajasthan's Khetri belt, situated approximately 47 km west of the study area, is another potential source of groundwater contamination. However, it's worth noting that the uranium concentration in the study area is lower compared to other places such as the Sohna fault line Gurugram, Sonipat, Bhiwani, Rewari, Western Haryana, and Rohtak[45,46]. A weak positive correlation (r = 0.107) was observed between the source depth and the uranium concentration, as indicated in Fig. 3. This correlation could be attributed to various factors including dilution, adsorption, geological conditions and geochemical reactions. As water permeates through the ground, it encounters various layers of rock and soil that act as natural filters, diluting the uranium concentration in the water. Deeper the water travels, the more layers it passes through, leading to anincrease in uranium concentration. Additionally, uranium has a tendency to adsorb onto solid surfaces, such as soil particles and rocks. As water moves through the ground, immobilizing some of the uranium. Furthermore, as water interacts with minerals, different geochemical reactions may precipitate uranium out of the water, further reducing its concentration. Table 2 outlines the statistical parameters for the analysis of uranium concentration in the water samples, including kurtosis and skewness.

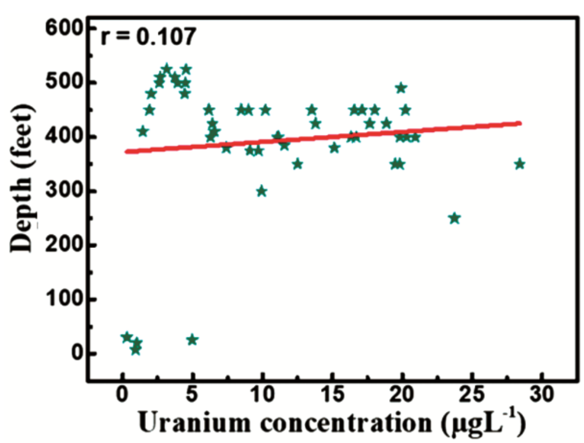

Fig. 3 — The scatter plot between the uranium concentration and the depth (feet) of the water source shows a positive correlation.

The studied data has been compared globally, and results are presented in Table 3. Uranium concentration in water samples is found to be lowest in European Kosovo[25], China[24], and New Mexico[47], while it reaches its highest level in Germany[23], and Ohio[26]. Notably, Turkey[48] exhibit uranium concentration approximately equal to the study area. Turkey geological composition comprising both igneous and metasedimentary rocks, may be contributing toits drinking water uranium levels being similar to those in our study area. Dhosi Hill, integral part of the Aravalli Mountain range, contains quartzite rocks, is pertinent to this observation. In Fig.4, a frequency distribution histogram displays the uranium concentration in drinking water samples from different locations. The univariate data set is accompanied by a Gaussian fit count (indicated in red), and the skewness indicates a longer right tail compared to the left. The kurtosis data set exhibit light tails, indicating a lack of outliers.

In Fig. 5, a frequency distribution illustrates the uranium content in water samples. About (30%) of uranium samples exhibita concentration of less than 5 μg l^{-1}, while approximately (52%)of samples have a concentration below 10 μg l^{-1}. This distribution falls within the WHO, 2011 which is 30 μg l^{-1} and align within the limit of AERB, 2004 which is

Table 3 — Uranium concentrations values in groundwater/well/river water samples around the world.

Serial no.	Country	Sources	Uranium concentration (μgl^{-1})	References
1	Germany	Tap water	0.015 – 8.54	[23]
2	China	Ground water	< 0.02 – 288	[24]
3	European, Kosovo	Drinking water	0.01 – 166	[25]
4	Ohio, USA	River water	0.3 – 3.9	[26]
5	Ghana	Ground water	< 0.001 – 266	[27]
6	New Mexico	Well water	Greater than 20	[47]
7	Turkey	River water	0.24 – 17.65	[48]
8	Switzerland	Drinking water	0.05 – 100	[51]
9	France	Surface water	0.35 – 74.4	[52]
10	India	Drinking water	< 0.2 – 4918	[53]

(60 µg l^{-1})[49,50]. Low level of uranium concentration may be due to negligible availabilities of industries, and predominantly alluvial plain in the study area.

Table 4 provides an overview of the annual effective dose values among different age groups in the present study area, and one can see a visual representation in Fig. 6 through a whisker box plot. According to ICRP (International Commission of Radiological Protection), parts age group in different age categories,annual ingestion dose for infant (0–6) months age group ranging from 0.11–8.3 µSv y^{-1} , and for (7–12) months ranging from 0.13–9.5 µSv y^{-1}; children with age group (1–3)years, and (4–8) years ingestion dose ranging from 0.2–15.4 µSv y^{-1}, 0.28–20 µSv y^{-1}; male age group (9–13) years, (14–18) years, and adult group dose ranging from 0.4–28.4 µSv y^{-1}, 0.5–39 µSv y^{-1}, and 0.6–43.8 µSv y^{-1}; female age group (9–13) years, (14–18) years, and adult group dose ranging from 0.3–24.8 µSv y^{-1}, 0.4–27.2 µSv y^{-1}, and 0.4–31.9 µSv y^{-1}; and pregnant women ingestion dose ranging from 0.5–35.5µSv y^{-1}. Notably, the male adult group registered the highest annual dose, which is 43.8 µSv y^{-1}. This could be attributed to the higher water consumption by the male adult group, which is 3.7 litres per day or 1350.5 liters per year, as shown in Table 4.Conversely, the infant age group displayed the lowest dose, which is 0.11µSv y^{-1}. This is because the daily water intake for infants is relatively low, approximately 0.7 l day^{-1} or 255.5 l y^{-1}, because some parameters like gender, age, and weight are dependent on waterintake[54]. It's important to highlight the maximum dose value in water which is 43.8 µSv y^{-1}, which is below the

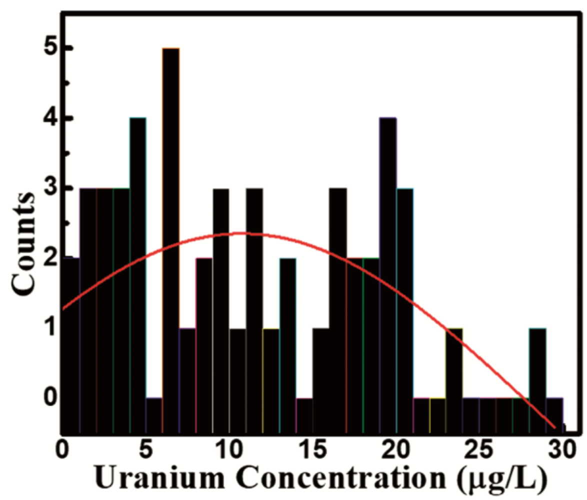

Fig. 4 — The distribution histogram with Gaussian fit counts (shown in red curve) presents an univariate data set of uranium concentration in groundwater of monitoring sites.

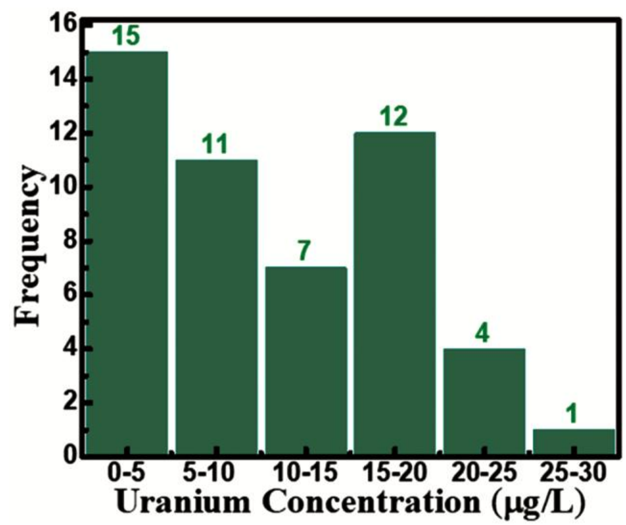

Fig. 5 — Frequency distribution of Uranium concentration in 50 water samples across Mahendergarh district by using LED Fluorimeter.

Table 4 — Statistical parameters used for estimation of Annual ingestion dose for different age groups due to drinking water of Mahendergarh, Haryana India.

Age groups		I ($LDay^{-1}$)	Minimum Annual effective dose (AED) ($µSvy^{-1}$)	Maximum (AED $µSvy^{-1}$)	Mean (AED $µSvy^{-1}$)
Infants	0-6 months	0.7	0.11	8.3	3.11
	7-12 months	0.8	0.13	9.5	3.6
Children	1-3 year	1.3	0.2	15.4	5.8
	4-8 year	1.7	0.28	20	7.6
Male	9-13 year	2.4	0.4	28.4	10.74
	14-18 year	3.3	0.5	39	14.76
	Adult	3.7	0.6	43.8	16.56
Female	9-13 year	2.1	0.3	24.8	9.39
	14-18 year	2.3	0.4	27.2	10.3
	Adult	2.7	0.4	31.9	12.1
Pregnancy	14-18 year	3.0	0.5	35.5	13.42

I = Daily water intake [39]

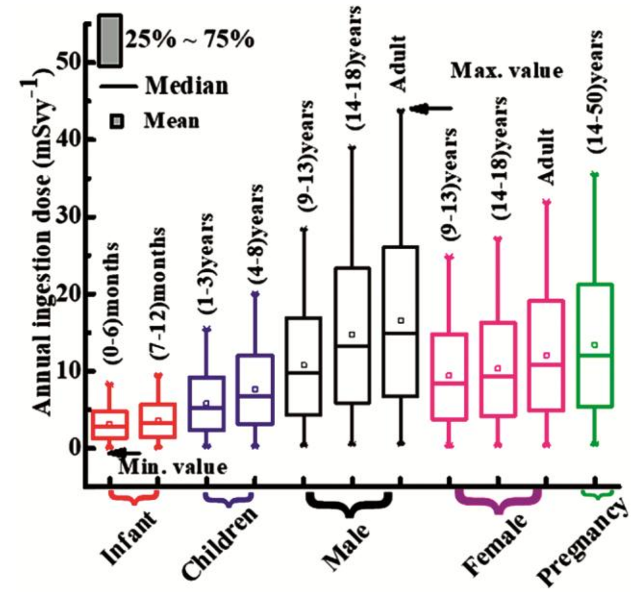

Fig. 6 — Whisker box chart for annual ingestion dose of different age groups, ▫ represents mean value of dose, – shows median values of dose for different age groups (infant dose in red, children in blue, male in black, female in pink, and pregnancy in green colour).

permissible limit for annual effective dose of (100 µSv y^{-1})[32]. When analysingcancer mortality and morbidity risk, we found values within a range of 10^{-5} and 10^{-6}, as shown in Table 2. These values are below the recommended limit for radiological risks, which is (10^{-3})[41]. The values for LADD range from 0.01 µg kg^{-1} day^{-1} to 0.81 µg kg^{-1} day^{-1}, with an average value of 0.31 µg kg^{-1} day^{-1}. This average falls below the recommended value by WHO (2011), which is 1 µg kg^{-1} day^{-1}. The maximum chemical risk, *i.e.*, 0.81 µg kg^{-1} day^{-1}, is identified in Sigra village, while the minimum LADD value is found in Palli village. HQ exceeds the recommended limit for Sigra(H-8) and Akoda village (H-47), which was 1.35 and 1.13 respectively, which is greater than 1. Both these villages lie periphery to the Aravalli Mountain range, with Sigra village beingsurrounded by Dhosi hills. Dhosi Hill is an extinct volcano standing at the northwest end of the Aravalli Mountain Range, exhibits all the properties of a perfect volcanic hill, including presence of lava emanates from eruptions and a crater. These features may be contributing to the elevated hazard quotient in these areas.

5 Conclusion

According to reports by WHO (2011), USEPA (2011), and AERB (2004), the measured concentration of uranium in drinking water samples is below the safe limit. It is determined that activity concentrations in the studied area are below the safe threshold at all locations. The annual effective dose for different age groups of humans is determined to be less than the WHO, 2004 limit. Further, the calculated values for the excess cancer risk are also within the safe limit range. For radiological cancer risks, mortality, and morbidity values below 10^{-3} are observed. Furthermore, Chemical toxicity risks (LADD) are also found below the limit as recommended by the WHO in 2011. Lastly, the hazard index value calculated for uranium in this area is less than one indicating that the studied area is safe and poses no threat to the health of its residents.

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Declaration

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.

Conflict of interest

The authors have no conflict of interest.

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