



Risk assessment of uranium in groundwater surrounding the Greater Noida industrial area, Uttar Pradesh, India

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ABSTRACT

Groundwater quality is an important concern for public health, particularly with respect to uranium contamination, which may contribute to radiation dose and chemical toxicity when used for drinking. An analysis of radiation levels in groundwater has been undertaken around Noida, Uttar Pradesh, India, using the LED Fluorimetry Technique. The concentration of uranium (U-238) in water samples obtained from submersible pumps, tube wells, and hand pumps in Noida is determined. The uranium concentration, averaging $10.62 \mu\text{g L}^{-1}$, along with the annual effective dose of $1.77 \mu\text{Sv y}^{-1}$, falls within the safety thresholds recommended by the World Health Organization (2004) and the Atomic Energy Regulatory Board (2004). The chemical toxicity and radiological impact of uranium in water have been assessed. To estimate radiation risks from natural radionuclides in groundwater, radiological health parameters were determined. Elevated activity levels of natural radionuclides in certain areas are attributed to factors such as regional geology, hydrology, and the nature of local industries.

1. Introduction

Radiation is present everywhere, and everyone is exposed to radiation originating from natural and man-made sources. Cosmic and terrestrial rays, including gamma, alpha, and beta rays, are the most common natural sources of radiation.

The solubilization of uranium raises significant concerns for groundwater quality, which is already under threat from rapid urbanization and global climate change (Vorosmarty et al, 2000). Across India and globally, millions of individuals consuming water contaminated with toxins face potential health risks. Furthermore, approximately 43 % of the world's groundwater is estimated to be utilized for irrigation purposes (Siebert et al, 2010). Research has shown that food crops irrigated with contaminated water can accumulate uranium (Hakonson-Hayes et al, 2002; Jeambrun et al, 2012), providing an

additional route of uranium exposure to humans through the food chain. Uranium in shallow groundwater is a concern across many Indian states, not just locally. According to a 2019-20 survey by the Central Ground Water Board, samples from shallow wells across India show uranium concentrations ranging from 0 to $2876 \mu\text{g/L}$, with many wells in states like Punjab, Haryana, Delhi, Telangana etc. exceeding the WHO guideline of $30 \mu\text{g/L}$. A study by Coyte et al. (2018) similarly showed widespread uranium contamination of groundwater resources across 16 Indian states, emphasizing that geological settings combined with anthropogenic stresses (e.g. over-pumping, nitrate inputs) are major controls.

Compared to surface water collected from a well, sub-surface water is generally safer to use and easier to handle. However, groundwater contains a number of chemicals that pose health risks to the population (Kumar et al, 2018). Groundwater is primarily used for drinking water in

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the study area. Through the processes of ingestion and inhalation, radionuclides from the food chain enter the human body, making the assessment of natural radiation levels in water a significant concern today. Unhealthy water is a major cause of kidney disease and mortality (Duggal et al., 2014, Henshaw et al., 1990).

It is necessary to assess the uranium level in the water of the study area used by the population from the perspective of health toxicity. The health implications of uranium exposure, particularly its chemical toxicity leading to nephrotoxic effects, are well documented worldwide (Leggett, 1989). Although radiological effects become significant at higher concentrations, chemical toxicity is the predominant risk at levels typically found in groundwater (Kathren and Burklin, 2008). Previous studies across India have reported elevated uranium levels in several regions: in Punjab, agricultural practices and phosphate fertilizers are major contributors (Mehra et al., 2007); in Rajasthan, the geological composition of the Aravalli hills plays a key role (Rani et al., 2013); in Haryana, granite-rich terrains such as the Tusham Hills are linked with uranium enrichment (Kansal et al., 2011); and in Kerala, monazite-bearing coastal sands influence groundwater radioactivity (BEN et al., 2012). Despite these findings, no systematic study has been undertaken in Greater Noida, a rapidly urbanizing and industrial hub in western Uttar Pradesh. The present work therefore, provides the first uranium concentration data for this region, addressing a critical gap in groundwater quality and health risk assessments. It is important to understand basic parameters and radioactivity in groundwater to assess potential health risks. Therefore, it becomes essential to evaluate uranium levels in the target region's water and to assess the associated potential health effects on residents, which may serve as a reference for future research.

2. The study area

Gautam Budh Nagar district is part of western Uttar Pradesh, also known as the New Okhla Industrial Development Authority (NOIDA), which is situated near the left bank of the Yamuna River and in proximity to the capital of India, Delhi. This district has developed into a modern industrial city near Delhi. Due to its status as an industrial hub, the population growth in Noida is extensive, estimated to be about half a million. Sample code and GPS locations are depicted in Table 1. The Gautam Budh Nagar district spans 1442 square kilometers, with the main feature being the industrialization of the area. According to the 2001 census, the district's total population was 1,105,292, with an average population density of 766 people per square kilometer. The study area is part of the Ganga-Yamuna Doab and is located in the Yamuna sub-basin, characterized by the presence of dunes, sandy ridges, ravines, and depressions. The area consists of Older Alluvium (Pleistocene age) and Newer Alluvium (Quaternary age). The lithology is characterized by an interbedded sequence of sand, silt, clay, and occasional gravel layers. These unconsolidated sediments overlay the more consolidated basement rocks of the Delhi Super-group. From a hydrogeological perspective, the primary aquifers in the region are these interconnected, multi-tiered sand layers within the alluvial sequence. The clay and silt layers act as aquitards, creating semi-confined to confined conditions. The groundwater flow is generally from the northeast to the southwest, following the regional slope of the terrain (Kundu et al., 2024). The Hindon River watershed covers most of the area (Alam and Umar, 2013). The Yamuna River and its tributaries, the Hindon River and Bhuriyanadi, drain the Gautam Budh Nagar district. Irrigation in the district is primarily provided by small irrigation systems such as tube wells, cavity tube wells, and drilled wells on occasion. Agriculture and industries are well-established in this area. The soil of the study area consists of sandy and loamy soil, making wheat, rice, and sugarcane the main crops, while millet is also planted in a few areas. The study location has a subtropical climate with moderate rainfall, where canals and tube wells are the main sources of irrigation; dairy farming is the second most adopted occupation in the rural area. A study map is

shown in Fig. 1.

3. Materials and methods

3.1. Sampling and preparation

A total of 35 water samples were collected from tube-wells, submersible pumps, and hand pumps in Noida, Uttar Pradesh (Fig. 1). All 35 water samples were collected during the post-monsoon season, i.e., August of the year 2024, to minimize variability due to seasonal hydrological changes. Sampling sites were selected based on regions where water is extensively used for crop irrigation, live-stock, and human consumption. The locations were chosen to ensure uniform coverage of the study area. Sample locations were recorded using a Garmin GPSMAP 66sr portable GPS device. Coordinates for each sampling point are provided in degrees, minutes, and seconds (D°M'S") format. All sampling points were carefully verified on-site to ensure they accurately represent the intended locations, avoiding potential contamination sources such as national highways or industrial areas. To maintain sample integrity, water was pumped for approximately 10 min before collection. Groundwater samples (500 mL) were collected in prewashed polyethylene bottles (rinsed with carbonated water). The larger volume ensured reserve sample availability for repeat measurements if required. To eliminate suspended particles, the water was filtered using 0.45 mm filter paper and then transferred into pre-cleaned 50 mL polyethylene bottles. The uranium concentrations in the collected water samples were analyzed at the Environmental Science Laboratory, Central University of Punjab, Bhatinda, India.

3.2. Instrumentation

The LED fluorimetry technique is employed to quantify uranium in liquid samples. In this method, an LED light is pulsed at high intensity for short intervals to excite the fluorescence of uranyl ions (Chahal et al., 2019, Panghal et al., 2017). For uranium measurement, a 200 mL aliquot of each sample was transferred into prewashed polyethylene bottles (rinsed with distilled water and then dried) to be used directly. To eliminate dust particles, the samples were filtered using Whatman Filter Paper No. 10. The uranyl ions in the solution were excited using the LED fluorimeter (Model No. LF-2a, Quantalase Enterprises Pvt. Ltd., Indore, India), which operates at an excitation wavelength of 405 nm. The device is capable of quantifying uranium concentrations in the range of 0.5–1000 µg/L, with a detection limit of 0.5 µg/L.

A 5 % sodium pyrophosphate solution ($\text{Na}_4\text{P}_2\text{O}_7 \cdot 10\text{H}_2\text{O}$) was prepared by dissolving 5 g of sodium phosphate in 100 mL of double-distilled water. Orthophosphoric acid (H_3PO_4) was then added dropwise until the pH reached 7. To perform the fluorescence measurement, approximately 6 mL of the water sample and 0.6 mL of the sodium pyrophosphate solution was placed in a cleaned cuvette. A blank sample, consisting of double-distilled water and the same fluorescing agent used for uranium quantification, was prepared to record blank counts. Quality control measures were adopted throughout the analysis. All polyethylene bottles were pre-cleaned with dilute nitric acid and rinsed with deionized water before sampling. Reagent blanks and deionized water blanks were analyzed alongside the groundwater samples to ensure no contamination or instrument drift. About 10 % of the groundwater samples were reanalyzed in duplicate, and the results agreed within ± 5 %. Each measurement was taken in triplicate, and the mean value was used for further calculations to ensure reproducibility. Prior to analyzing the groundwater samples, the calibration mode was used. Standard uranium solutions (2.5, 5, 10, and 90 µg L⁻¹) were first measured to generate a calibration curve, which was then applied to determine uranium concentrations in the groundwater samples from their fluorescence intensities.

Table 1

Lifetime stochastic health effect, LTADD, HQ, LTRC Cancer Mortality, and LTRC Cancer Morbidity in water samples from the study area.

S. No.	Sample Code	Sample Area	Latitude & Longitude	Groundwater Depth (m)	Uranium Concentration $\mu\text{g L}^{-1}$	Annual Effective Dose ($\mu\text{Sv y}^{-1}$)	Lifetime Stochastic Health Effect ($\times 10^{-6}$)	LTADD	HQ	LTRC Cancer Mortality ($\times 10^{-6}$)	LTRC Cancer Morbidity ($\times 10^{-6}$)
1	N-1	Prajapati Road	28°32'51"N 77°23'16"E	33	23.54 $\pm$ 1.43	3.92	0.29	1.84	1.53	0.33	0.65
2	N-2	Sector 81	28°33'03"N 77°23'39"E	36	9.57 $\pm$ 0.67	1.59	0.12	0.75	0.62	0.13	0.26
3	N-3	RP Complex	28°33'37"N 77°22'11"E	24	9.93 $\pm$ 0.91	1.65	0.12	0.77	0.65	0.14	0.27
4	N-4	Kuleshra	28°31'26"N 77°26'17"E	14	6.27 $\pm$ 0.41	1.04	0.08	0.49	0.41	0.9	0.17
5	N-5	Sharma Market, Surgjdos	28°30'45"N 77°28'14"E	15	1.3 $\pm$ 0.21	0.22	0.02	0.10	0.08	0.02	0.04
6	N-6	Indian Public School, Nagla Charandas, Phase 2	28°32'32"N 77°24'20"E	34	12.39 $\pm$ 1.67	2.06	0.15	0.97	0.81	0.17	0.34
7	N-7	Union Bank of India, Dadri Road, Sector 102	28°33'38"N 77°22'08"E	27	13.23 $\pm$ 1.04	2.20	0.16	1.03	0.86	0.19	0.37
8	N-8	Shiv Road, Goyal Colony, Khadar, Sector 82	28°32'08"N 77°23'03"E	32	3.02 $\pm$ 0.14	0.50	0.04	0.24	0.20	0.4	0.08
9	N-9	Gejha, Sector 93	28°31'31"N 77°23'15"E	29	20.86 $\pm$ 1.21	3.47	0.25	1.63	1.36	0.29	0.58
10	N-10	Shiv Mandir, Gejha, Sector 93	28°31'28"N 77°23'20"E	31	3.44 $\pm$ 0.35	0.57	0.04	0.27	0.22	0.05	0.1
11	N-11	Block-C, Sector 108	28°31'35"N 77°22'43"E	30	1.53 $\pm$ 0.25	0.25	0.02	0.12	0.10	0.02	0.04
12	N-12	Sector 101	28°33'01"N 77°22'54"E	22	22.36 $\pm$ 1.98	3.72	0.27	1.74	1.45	0.31	0.62
13	N-13	Hindon Vihar	28°33'30"N 77°22'35"E	26	14.45 $\pm$ 1.12	2.41	0.18	1.13	0.94	0.2	0.4
14	N-14	Rajput Colony	28°33'36"N 77°22'28"E	28	16.77 $\pm$ 0.89	2.79	0.20	1.31	1.09	0.24	0.46
15	N-15	Kailash Chand & Sons Jewellers, Sector 49	28°33'50"N 77°22'16"E	24	12.27 $\pm$ 0.72	2.04	0.15	0.96	0.80	0.17	0.34
16	N-16	Block B, Sector 81	28°32'53"N 77°24'07"E	37	4.7 $\pm$ 0.31	0.78	0.06	0.37	0.31	0.07	0.13
17	N-17	Amrapali Princely Estate	28°34'23"N 77°20'09"E	25	13.35 $\pm$ 0.23	2.22	0.16	1.04	0.87	0.19	0.37
18	N-18	Ved Plaza, Salarpur	28°32'27"N 77°23'19"E	36	20.34 $\pm$ 1.90	3.39	0.25	1.59	1.32	0.29	0.56
19	N-19	Sabzi Mandi	28°31'54"N 77°25'22"E	30	10.11 $\pm$ 0.18	1.68	0.12	0.79	0.66	0.14	0.28
20	N-20	Masjid, Sector 106	28°32'08"N 77°23'17"E	29	8.2 $\pm$ 0.32	1.37	0.10	0.64	0.53	0.12	0.23
21	N-21	Jeetram, Sector 47	28°33'08"N 77°22'17"E	32	17.04 $\pm$ 1.07	2.84	0.21	1.33	1.11	0.24	0.47
22	N-22	Bhangel, Sector 88	28°32'00"N 77°25'17"E	30	10.13 $\pm$ 0.98	1.69	0.12	0.79	0.66	0.14	0.28
23	N-23	Sector 115	28°34'03"N 77°24'28"E	22	13.5 $\pm$ 0.73	2.25	0.16	1.05	0.88	0.19	0.37
24	N-24	Sarfabad Road	28°34'50"N 77°23'09"E	31	11.88 $\pm$ 0.99	1.98	0.14	0.93	0.77	0.17	0.33
25	N-25	Sector 125	28°32'37"N 77°19'51"E	29	3.3 $\pm$ 0.19	0.55	0.04	0.26	0.21	0.05	0.09
26	N-26	Sector 124	28°32'54"N 77°19'43"E	29	15.81 $\pm$ 1.2	2.63	0.19	1.23	1.03	0.22	0.44
27	N-27	Sector 126	28°32'19"N 77°20'22"E	28	10.17 $\pm$ 0.96	1.69	0.12	0.79	0.66	0.14	0.28
28	N-28	Sector 82	28°31'45"N 77°23'28"E	33	5.22 $\pm$ 0.47	0.87	0.06	0.41	0.34	0.07	0.14
29	N-29	Kaushamb, Sector 8	28°35'42"N 77°19'41"E	30	13.77 $\pm$ 0.88	2.29	0.16	1.07	0.89	0.19	0.37
30	N-30	Mangtu Colony, Sector 101	28°33'00"N 77°23'08"E	31	3.85 $\pm$ 0.54	0.64	0.03	0.30	0.25	0.04	0.07

(continued on next page)

Table 1 (continued)

S. No.	Sample Code	Sample Area	Latitude & Longitude	Groundwater Depth (m)	Uranium Concentration $\mu\text{g L}^{-1}$	Annual Effective Dose ($\mu\text{Sv y}^{-1}$)	Lifetime Stochastic Health Effect ($\times 10^{-6}$)	LTADD	HQ	LTCR Cancer Mortality ($\times 10^{-6}$)	LTCR Cancer Morbidity ($\times 10^{-6}$)
31	N-31	Sector 45	28°33'16"N 77°21'05"E	26	6.45 $\pm$ 0.59	1.07	0.05	0.50	0.42	0.06	0.11
32	N-32	Sector 49	28°30'46"N 77°28'48"E	19	4.1 $\pm$ 0.28	0.68	0.09	0.32	0.27	0.1	0.2
33	N-33	Shani Mandir, Sector 28	28°34'23"N 77°20'09"E	24	4.5 $\pm$ 0.16	0.75	0.09	0.35	0.29	0.11	0.21
34	N-34	Barolla, Sector 24	28°35'14"N 77°21'01"E	31	5.1 $\pm$ 0.18	0.85	0.10	0.40	0.33	0.11	0.22
35	N-35	Salarbur, Sector 106	28°32'13"N 77°23'25"E	27	17.4 $\pm$ 1.51	2.89	0.17	1.36	1.13	0.2	0.39

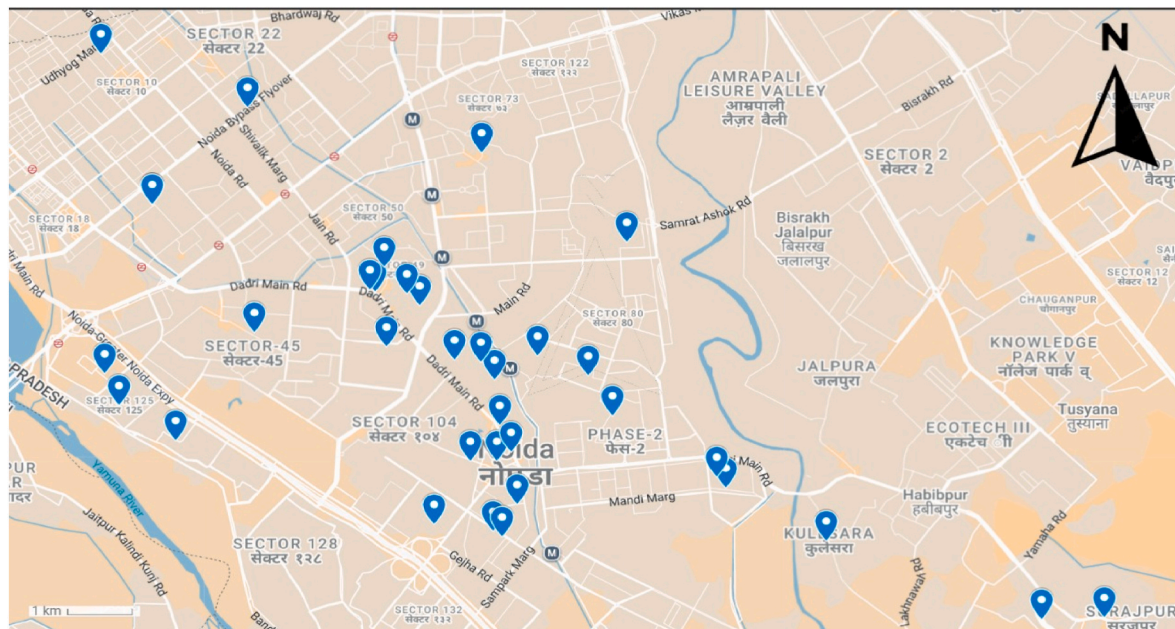


Fig. 1. Map of various locations of water samples collected from the study area.

3.3. Chemical concentration of uranium

Details concerning the instrument's calibration, the analytical process, and quality control are provided elsewhere (Ajay et al, 2016). For the measurement of uranium, the following equations were used:

$$CF = \frac{\text{Uranium concentration in standard solution } (\mu\text{g L}^{-1})}{\text{Fluorescence of standard} - \text{Fluorescence of water}} \quad (1)$$

Where.

- CF: Calibration factor $\frac{\mu\text{g L}^{-1}}{\text{a.u.}}$
- UC = CF $\times$ FL
- UC: Uranium concentration in the unknown sample [$\mu\text{g L}^{-1}$]
- FL: Fluorescence from the sample [a.u.]

3.4. Activity concentration of uranium

The unit conversion factor $1 \mu\text{g L}^{-1} = 0.02528 \text{ Bq L}^{-1}$ was used for calculating the activity concentration of uranium (U_a) (Rani et al, 2013; Sahoo et al, 2010). India) (USEPA, 1990).

3.5. Annual ingestion dose (AID) due to uranium

The annual effective dose (D_u) of uranium from drinking water samples is calculated using the following equation (Alam and Umar, 2013; Panghal et al, 2019):

$$D_u (\mu\text{Sv y}^{-1}) = U_a \times ED \times 10^3 \times 1480 \text{ y}^{-1} \quad (3)$$

where.

- U_a is the activity concentration of uranium (Bq L^{-1}),
- ED is the effective dose per unit intake via ingestion ($4.5 \times 10^{-5} \text{ mSv Bq}^{-1}$) and
- The average daily water consumption is 4.05 L per person (Jain et al, 1995).

3.6. Cancer risk due to uranium

Carcinogenic risk is determined by multiplying the ongoing radiation dose exposure by the corresponding risk factor. The excess lifetime cancer risk (LTCR) associated with uranium ingestion from water is computed using the formula outlined by the United States Environmental Protection Agency (USEPA, 2000):

$$LTCR = U_c \times R_f \quad (4)$$

- Where.

- U_c is the uranium concentration, and
- R_f is the risk factor (per Bq L⁻¹). The risk factor (R_f) is defined as:

$$R_f = R_c \times I_R \times T_E \quad (5)$$

- R_c is the hazard coefficient for ingestion,
- I_R is the ingestion rate (4.05 Lday⁻¹) for an adult in the study area, and
- T_E is the exposure time (65 years for an adult in India) (USEPA, 1990).

The hazard coefficient is used to assess the risks of mortality or morbidity per unit intake of a radionuclide for internal exposure or per unit dose for external exposure (Giri and Jha, 2012, USEPA, 1991). For uranium, LTCR for Cancer mortality and LTCR for cancer morbidity, the risk coefficients for cancer mortality and morbidity are 1.13×10^{-9} Bq⁻¹ and 1.73×10^{-9} Bq⁻¹, respectively.

3.7. Chemical toxicity risk

The chemical toxicity hazard of a component is assessed based on the lifetime average daily dose (LTADD), which quantifies the amount of a chemical substance ingested per kilogram of body weight per day (USEPA 2000).

$$LTADD = \frac{EP}{MT} \times \frac{I_R}{W} \times EPF \times LET \quad (6)$$

where.

- EP represents the exposure concentration ($\mu\text{g L}^{-1}$),
- EPF is the exposure frequency (365 days per year) (USEPA, [1991]), worst case is considered,
- LET stands for life expectancy (65 years) (USEPA 2003),
- MT is the mean time (23,725 days), and
- W is the body weight (53 kg) (AERB 2004).

The hazard quotient (HQ) is a tool for assessing the daily intake of uranium relative to the reference dose, offering a measure of the chemical risk. The reference dose (RfD) indicates the maximum daily intake of uranium that is unlikely to cause adverse health effects over a lifetime. The uranium Hazard Quotient (HQ) via water consumption is determined as (USEPA 2000):

$$HQ = \frac{LTADD}{RfD} \quad (7)$$

The hazard quotient (HQ) serves as the standard unit for evaluating the chemical risk of a substance. The reference dose (RfD), set at $1.2 \mu\text{g kg}^{-1} \text{ day}^{-1}$, refers to the daily intake of uranium that is considered safe without significant health risks over an individual's lifetime.

4. Results and discussion

Uranium levels in groundwater and their related health risks are influenced by the area topography and geological features. Table 1 shows the uranium concentration, annual effective dose, and geographic coordinates of various locations within the study region. In this study, uranium concentrations ranged from 1.3 (N-5, Sharma Market, Surgidos) to $23.54 \mu\text{g L}^{-1}$ (N-1, Prajapati Road), with an average of $10.62 \mu\text{g L}^{-1}$. These values lie below the regulatory limits of $30 \mu\text{g L}^{-1}$ (WHO, 2004; USEPA, 2000) and $60 \mu\text{g L}^{-1}$ (AERB, 2004, 2008), but are higher than the more conservative guideline values proposed by UN- SCEAR ($9 \mu\text{g L}^{-1}$) (Radiation UNSCEAR 1988) and ICRP ($1.9 \mu\text{g L}^{-1}$) (Wrixon, 2008). This comparison highlights that while the groundwater in the

study area meets national and international regulatory standards, a fraction of samples approach or exceed the lower limits set by UNSCEAR and ICRP, suggesting that uranium concentrations in the study area are generally low and unlikely to pose significant health risks.

This spatial distribution map (Fig. 2) illustrates uranium concentration levels in groundwater across the Study Region. The map uses a smooth gradient ranging from blue (low concentration) to deep red (high concentration). The central zone, around sampling locations N-9, N-12, N-18, and N-29, shows the highest uranium concentrations (red-orange areas). These elevated zones lie near industrial corridors and densely urbanized areas of Greater Noida and Dadri, indicating a possible anthropogenic influence. The northern and eastern regions (yellow zones) reflect lower uranium levels, corresponding to less industrialized or more open areas. High uranium concentrations overlap with industrial clusters located along the Noida–Greater Noida Expressway, Dadri Road, and Yamuna Expressway. These corridors host metal fabrication, electronics, and construction industries, which may contribute trace uranium through effluent discharge or leaching from construction debris. Geologically, Noida and Dadri fall under Quaternary alluvium composed of sand, silt, and clay, with occasional kankar (calcareous nodules) — these can facilitate uranium mobilization through groundwater due to carbonate complexation. Areas closer to the Yamuna River (western boundary) show slightly lower concentrations, possibly due to dilution effects from river recharge.

The observed fluctuations in uranium values between wells can be attributed to variations in aquifer lithology, depth, and redox conditions rather than to strong anthropogenic contributions.

Comparable recent work in Deoghar district, Jharkhand, found uranium in groundwater ranging from 0.10 to $11.30 \mu\text{g L}^{-1}$ in pre-monsoon and 0.15 – $6.50 \mu\text{g L}^{-1}$ in post-monsoon samples, with most values well below WHO limits; the authors attribute low uranium levels largely to limited uranium-bearing lithologies rather than anthropogenic inputs (Srivastava et al, 2022).

Similarly, risk assessment around proposed uranium mining areas in East Singhbhum, Jharkhand, reported radiological and chemical risks from uranium ingestion within acceptable limits (excess lifetime cancer risk 1×10), even for the higher measured concentrations; this suggests that concentrations like those observed here are unlikely to present high health risks under current conditions (Giri and Jha, 2012). The distribution of uranium concentrations is approximately symmetrical around the mean, with negative kurtosis, indicating a platykurtic distribution. Unlike a normal distribution, this reflects a flatter peak and thinner tails, meaning fewer extreme values and a higher concentration of samples around the mean. The slight positive skewness (0.35) further suggests that while most groundwater samples fall near the average, a few locations show elevated uranium levels. Such statistical behavior highlights spatial heterogeneity in the study area: uranium contamination is generally moderate and well within guideline values, but localized pockets of higher concentration exist. From a risk assessment perspective, this distribution implies that monitoring should not only focus on overall averages but also on site-specific variations, since even a small number of outliers may pose health risks to local populations.

In comparison to the southwest coast district of Kerala, India, where uranium concentrations ranged from $0.31 \mu\text{g L}^{-1}$ to $4.92 \mu\text{g L}^{-1}$ (Ben et al, 2012), the values observed in the present study are higher. The southwest coast receives radioactivity from monazite beach sands, leading to a non-uniform distribution of uranium. In Punjab, the widespread use of phosphate fertilizers and industrial discharge contribute to the elevated uranium concentrations (Mehra et al, 2007). In Rajasthan, uranium levels are influenced by the geological composition of the Aravalli hills, which include phyllite, shale, marble, quartz, and gneiss (Rani et al, 2013). Similarly, elevated uranium levels in Haryana are attributed to granite from the Tusham Hills (Kansal et al, 2011) and leaching from the Yamuna River. Southern India has the highest uranium concentrations (Brindha et al, 2011).

The average uranium concentration in the current study is lower

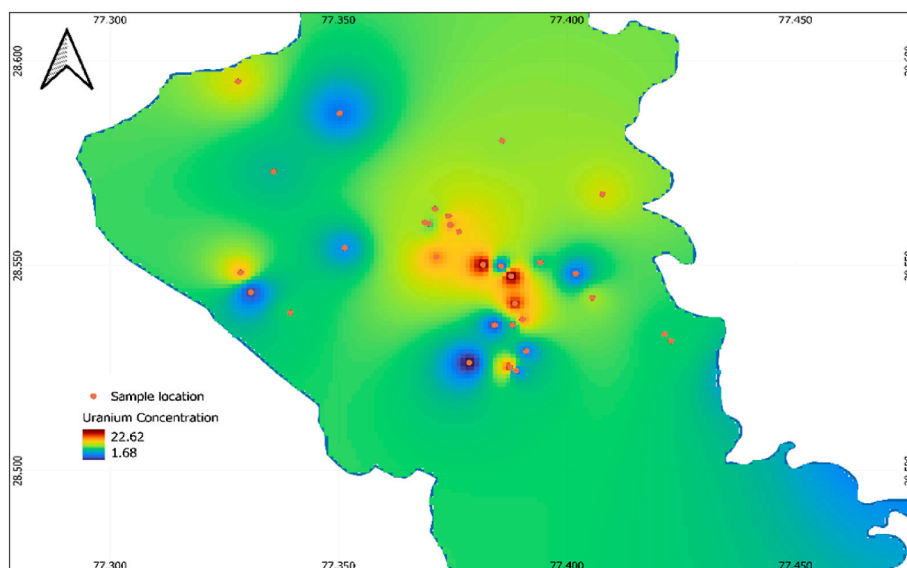


Fig. 2. Spatial distribution map illustrates uranium concentration levels in groundwater across the Study Area.

than that observed in Jaduguda, where the mean concentration was $15.3 \mu\text{g L}^{-1}$. Jaduguda is recognized for its significant U-238 content and is abundant in mineral deposits and uranium mines (Sahu et al., 2014). In Greater Noida, the alluvial aquifers underlying the Yamuna-Hindon Doab are composed of unconsolidated sands, silts, and clays under phreatic and semi-confined conditions (Saleem et al., 2018). These shallow aquifers are influenced by redox conditions, bicarbonate/carbonate chemistry, pH, and dissolved oxygen, all of which affect uranium mobility: under oxidizing and bicarbonate-rich rich conditions, uranium in hexavalent form dissolves and leaches more readily from sediments. Groundwater depletion in many parts of Noida (falling water tables) reduces dilution and increases residence time, thereby potentially raising uranium concentration even in regions with limited anthropogenic input. Agricultural practices may contribute modestly: fertilizers (especially phosphate fertilizers) may contain trace uranium; soil leaching enhanced by nitrates and excessive irrigation can mobilize uranium. Industrial discharge, though not definitively measured in the present study, is a possible source in areas near river basins such as the Hindon, where industrial effluents are known to worsen overall groundwater chemistry (metals, salts, organic matter), which may indirectly affect uranium behavior. Nevertheless, recent studies in Indian contexts report that even in industrial or mixed land-use areas, documented uranium discharge is seldom a dominant source; geological and hydro-chemical factors (e.g., host rock uranium content, groundwater pH/redox, carbonate complexation) are more often the controlling variables. Observed that in Deogarh, Jharkhand, uranium concentrations remained below guideline limits and were tied to lithological sources rather than industrial contamination (Srivastava et al., 2022). In analogous to the same study, authors emphasize that assertions of river-groundwater interaction influencing uranium levels are made only where river water uranium data, hydraulic gradients, or flow analyses are available. The elevated uranium values in some samples in Noida compared to others may thus be due to local lithological variations (sediment composition), depth of wells, groundwater-table decline, and proximity to sources of oxidants or pollutants that enhance uranium solubility, rather than major industrial uranium discharge.

The Yamuna River traverses various geological formations, including rocks and soils within hydrological systems that harbor notable concentrations of radionuclides from the U-238 and Th-232 series. These radionuclides are primary sources of radioactivity, which could potentially harm human health (UNSCEAR, 1993). The presence of

radioactivity in the river water results in both internal and external exposure. Internal exposure occurs through the ingestion and inhalation of radionuclides, while external exposure arises indirectly through their incorporation into the food chain (Amrane and Oufni, 2017). In India, within the western state of Uttar Pradesh (UP), the River Hindon flows as a major tributary of the Yamuna River. As it passes through urban and industrial regions, it collects a substantial amount of waste. This study focuses on determining the levels of natural radioactivity in the river water and assessing their effects on residents living near the Hindon River.

Literature indicates that the activity of uranium is primarily influenced by the geography of the area. The Hindon River, along with the numerous industries in the region, acts as a significant source of radioactivity, heavy metals, and minerals. Variations in uranium activity in groundwater are primarily attributed to the heterogeneous lithology (Choubey et al., 2003; Singh et al., 2017) and the impact of the Hindon and Yamuna Rivers. Although some sampling locations are situated near the Hindon River, this study did not include measurements of uranium in river water or hydrological connectivity analyses. Therefore, any potential influence of river water on groundwater uranium levels remains speculative and cannot be confirmed without supporting data. Additionally, the use of phosphatic fertilizers in local agriculture could be contributing to the increased uranium levels in groundwater (Sun et al., 2020). This suggests that the uranium concentration may result from chemical processes or reactions related, to some degree, to the natural radioactivity of the local sediments (Ajay et al., 2016; Kaur et al., 2019). Groundwater samples from villages situated on plain terrain and further from the Hindon River exhibited lower uranium concentrations. Table 1 presents the annual intake dose (AID) due to uranium-238 ingestion through water, ranging from 0.22 to $3.92 \mu\text{SvY}^{-1}$, with an average value of $1.77 \mu\text{SvY}^{-1}$, which is within the safe limits set by WHO (2004).

The lifetime hazard refers to the probability of radiation-induced health effects within a population over the course of their lifetime. Excell Life time cancer risk LTR for cancer mortality (CMT) is often quantified as the number of cancer-related deaths per 100,000 individuals (Ajay et al., 2016). The lifetime stochastic health effects, including LTADD, HQ, LTR (CMT), and cancer morbidity LTR (CMB), are outlined in Table 1. The lifetime cancer risk LTR (CMT) hazard spans from 0.016×10^{-6} to 0.29×10^{-6} . An alternative measure to estimate the overall risk of developing radiogenic cancer, known as the slope factor, provides an estimation irrespective of whether the cancer is fatal (Giri and Jha, 2012). Morbidity, which signifies the unhealthy state

due to malignancies in a population, is another health indicator (Singh et al., 2014). In the study area, the LTCR (CMT) from groundwater ingestion ranged from 0.036×10^{-6} to 0.65×10^{-6} , with a mean value of 0.29×10^{-6} , as displayed in Table 2. The LTCR(CMB) in the region ranged from 0.018×10^{-6} to 0.33×10^{-6} , with an average of 0.15×10^{-6} . Table 2 provides descriptive statistics for the annual effective dose, LTADD, and HQ, showing that the average values for LTCR(CMT) and LTCR(CMB) hazards fall within the recommended limit of 10^{-3} for radiation risks. Fig. 3 represent comparison of health risk parameters with associated uncertainties across different location codes. The plotted values represent the estimated lifetime stochastic health effect, LTCR cancer mortality, and LTCR cancer morbidity ($\times 10^{-6}$). Error bars indicate the corresponding uncertainty derived from propagated parameter errors, reflecting the variability and confidence in each estimate. It should be noted that parameters such as annual effective dose, LTADD, HQ, and cancer risk is derived directly from uranium concentration and hence follows the same statistical distribution. These statistics are presented here not as independent measures, but to provide clarity and allow readers to interpret the magnitudes and variability of radiological and chemical health risks without recalculating from uranium values. The primary health risk linked to uranium consumption stems from its toxicological effects. Chemical toxicity refers to the potential of a substance to damage organs like the liver and kidneys or interfere with biochemical processes, such as blood circulation. The LTADD values varied from 0.10 to $1.84 \mu\text{g kg}^{-1} \text{day}^{-1}$, with an average of $0.82 \mu\text{g kg}^{-1} \text{day}^{-1}$. Of the total samples, only 37.14 % surpassed the LTADD threshold of $1.0 \mu\text{g kg}^{-1} \text{day}^{-1}$, as recommended by WHO (2004). The HQ values ranged from 0.08 to 1.53, with a mean value of 0.69.

The intake of uranium-contaminated water poses a chemical risk, as indicated by the estimated HQ values. If the measured HQ value is less than 1, it suggests that there is no significant risk to the local population from uranium in the water. Most of the samples, except 22.85 % samples, have HQ values below the threshold recommended by USEPA (2003). Salapur's HQ of 1.53 (Prajaapati Road, Ved Plaza, Sector 101) indicates chemical risk above the conservative reference dose at that sampling point; this appears to be a local anomaly. Geological/hydro-geochemical controls in the Yamuna–Hindon alluvium, and possibly agricultural fertilizer inputs, are the most plausible explanations. Given the known heavy pollution of the Hindon/drain network in the district and the absence of river/effluent data in this study, industrial or river influences cannot be confirmed here. We therefore recommend (a) that Salapur residents use treated water as a precaution, and (b) targeted follow-up sampling (river/drain effluents, industrial effluents, fertilizer/soil assays) and isotopic analyses to apportion sources before any remediation program is designed. Overall, these findings indicate that uranium does not pose a significant negative health impact on the population in the study area. Although all measured uranium concentrations were below the WHO (30 $\mu\text{g/L}$) and AERB (60 $\mu\text{g/L}$) guideline limits, risk assessments (AID, HQ, and cancer risk) were performed as

part of a standardized radiological evaluation framework. Such assessments allow comparison with other regional and global studies and confirm quantitatively that the risks associated with uranium ingestion remain negligible in the study area. Importantly, the results indicate that uranium exposure levels are well within safe limits and pose no significant health hazard to residents.

5. Conclusion

This study provides information about radiation levels in water and their radiological effects on the population in the study area. Overall, this investigation contributes to understanding the behavior and distribution of radioactive elements and their isotopes in groundwater from Noida, Uttar Pradesh. In the study area, uranium concentrations are significantly lower than the permissible levels set by the Indian Atomic Energy Regulatory Board (AERB, 2004) and align with the guidelines provided by USEPA (2003) and UNSCEAR (2006). This emphasizes the importance of evaluating the potential risks of natural radiation exposure for the residents of the region. The observed radiation dose is well below the recommended thresholds. Although chemical effects from U-238 are detected in some samples, the average concentration remains within safe limits. Consequently, the chemical toxicity and radiological risks associated with uranium in the study area's water are minimal, making it considered safe for drinking. The findings indicate that uranium concentrations in the groundwater of the study area are within the safety limits prescribed by national and international guidelines, confirming that the water is currently safe for drinking. Nevertheless, ongoing monitoring is advisable to account for potential seasonal or long-term variations, thereby ensuring sustained protection of public health. A limitation of this study is that radon concentration and its annual effective dose were not analyzed. The results presented here provide a useful reference for policymakers and researchers, and future investigations should include additional radionuclides such as uranium, thorium, and potassium in soil, as well as radon and thoron levels in dwellings, to obtain a more comprehensive assessment of radiological exposure. A limitation of the present study is that uranium concentrations were assessed from a single sampling campaign; seasonal variability was not addressed. Future investigations should incorporate seasonal sampling to capture potential fluctuations in uranium levels.

CRedit authorship contribution statement

Narender Singh: Writing – original draft, Methodology, Data curation. **Sreejan Rayhan:** Writing – original draft, Methodology. **Amanjeet Panghal:** Writing – original draft, Methodology. **Rekha Dhiman:** Writing – original draft, Methodology, Formal analysis. **Navish Kataria:** Writing – review & editing, Methodology. **Suneel Kumar:** Writing – review & editing, Methodology. **Ranjeet Singh:** Writing – review & editing. **Balvinder Singh:** Writing – review & editing, Methodology. **Lalit Saini:** Writing – review & editing.

Table 2

Statistical parameters for uranium concentration, annual effective dose, lifetime stochastic health effect, LTADD, HQ, cancer mortality, and cancer morbidity.

Statistical Parameter	Uranium Concentration ($\mu\text{g/L}$)	Annual Effective Dose (μSvY^{-1})	Lifetime Stochastic Health Effect ($\times 10^{-6}$)	LTADD ($\mu\text{gkg}^{-1}\text{day}^{-1}$)	HQ	LTCR Cancer Mortality ($\times 10^{-6}$)	LTCR Cancer Morbidity ($\times 10^{-6}$)
Arithmetic Mean	10.62 ± 0.76	1.77	0.13	0.82	0.69	0.15	0.29
Max Value	23.54 ± 1.43	3.92	0.29	1.84	1.53	0.33	0.65
Min Value	1.3 ± 0.21	0.22	0.016	0.10	0.08	0.018	0.036
STDEV	6.03	1.00	0.073	0.48	0.40	0.085	0.17
Sample Variance	36	1.01	0.0054	0.23	0.16	0.0072	0.028
Geometric Mean	8.57	1.43	0.104	0.66	0.55	0.12	0.24
Median	10.13	1.69	0.12	0.79	0.66	0.14	0.28
Skewness	0.35	0.35	0.40	0.37	0.37	3.08	0.36
Kurtosis	-0.54	-0.54	-0.46	-0.77	-0.77	13.37	-0.53

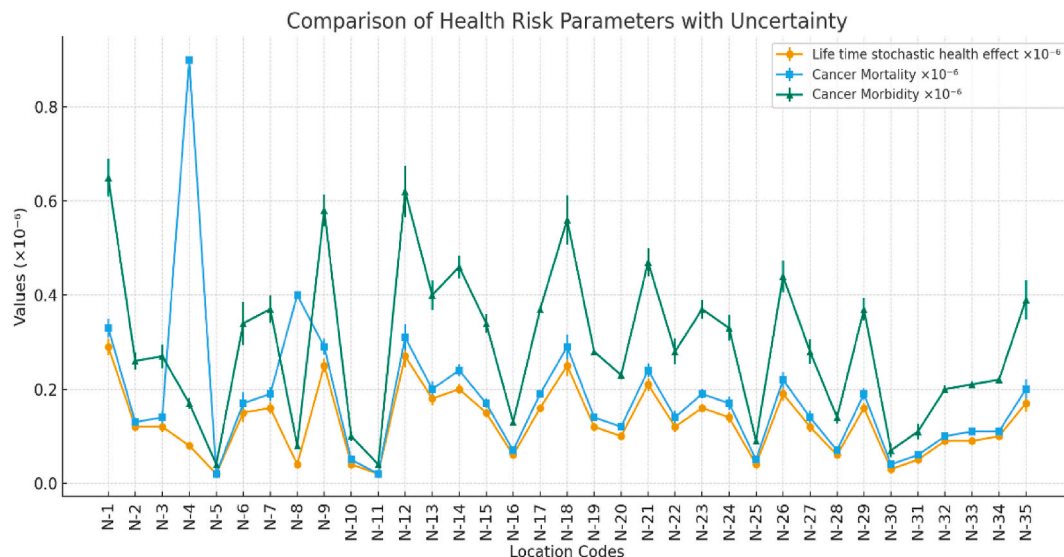


Fig. 3. Health Risk parameters with Uncertainty in Sample Areas.

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Declaration of competing interest

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

Data availability

No data was used for the research described in the article.

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