Estimation of uranium in groundwater and assessment of age-dependent radiation dose in Nalbari district of Assam, India

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Abstract

Uranium concentration has been estimated in 31 groundwater samples collected from the Nalbari district of Assam in pre-monsoon and post-monsoon season. Fourteen other water quality parameters have also been monitored to study their correlation with uranium. The uranium concentration varies from 0.3 to 7.1 µg/L with the mean value of 2.15 µg/L in pre-monsoon and 0.6–10.3 µg/L with the mean value of 2.75 µg/L in the post-monsoon season. The higher concentration of uranium in post-monsoon may be ascribed to the dissolution of uranium from soil sediments in the rainy season. It has been observed that the uranium content in both seasons is far lower than the WHO (2011) permissible limit of 30 µg/L. In both seasons, nitrate, sulphate, and especially phosphate show a positive correlation with uranium, which may be due to different agricultural activities. Agricultural nitrate and phosphate fertilization might be the carrier of uranium in groundwater through dissolution. For all life stage groups, the annual effective dose was appeared to be far below the WHO (2011) prescribed limit of 100 µSv/y. In consideration to adults, the ingestion dose for infants was turned out to be higher. The carcinogenic and non-carcinogenic risk was less than the permissible limits for both children and adults. Both dose value and risk indices were found higher in the post-monsoon season.

Keywords Uranium · Effective dose · Carcinogenic risk · Non-carcinogenic risk · Nalbari district

1 Introduction

Groundwater is the main drinking water source in rural and urban India. Due to rapid urbanization, industrial development, enormous chemical fertilizers use, and other human activities, the groundwater becomes polluted. According to the World Health Organization, 80% of human disease occurs because of the deteriorating quality of drinking water. The primary concern about uranium contamination in drinking water is that uranium acts as chemically and radiologically toxic radioactive pollutants. The continuous exposure of uranium through drinking water leads to potential health risks to humans. Several studies have been done to estimate the probable health hazard due to the intake of groundwater contaminated with uranium

[1–6]. Uranium originates from various anthropogenic activities such as mining, milling, mineral sands, and ores; fertilizer manufacturing [7–10] may be responsible for its groundwater presence.

Uranium occurs in various oxidation states, but hexavalent and tetravalent are the most dominant states of uranium. The hexavalent state is especially important in water due to its solubility because the tetravalent state is almost insoluble in water. The hexavalent form of uranium is commonly found in the form of uranyl ion UO_2^{2+} . Uranium mainly enters human tissues through the air, water, food, and other accidental and occupational exposures. Uranium intake through air and water is typically low, but most input can be through drinking water because it depends on its source's circumstances. Water with uranium

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content above 30 µg/L [11] is not suggested for drinking purposes as on continuous intake; it can cause damage to internal organs like kidney [12, 13] and bones [14].

Physico-chemical parameters (pH, electrical conductivity, TDS, ORP, etc.) of water are essential to provide important firsthand unaltered information about how much the water is suitable for drinking purposes [8]. The pH is monitored to assess human and aquatic environment health, drinking water sources, irrigation sources, intake, and discharges of the industries. Total dissolved solids (TDS) are the small amounts of inorganic salts and organic matter solvated in water. The water's capacity to oxidize the contaminants is termed as Oxidation Redox Potential (ORP). Though there is no standard for ORP by WHO, anything that shows ORP less than 550 mV is extraordinarily strong and is considered non-drinkable. Anions such as SO_4^{2-} , NO_3^- , F^- also play a vital part in determining the quality of drinking water. A high amount of sulphate can cause intestinal disorders and diarrhoea [15]. Problems like blue baby disease or methemoglobinemia can be caused by a nitrate content of more than 45 mg/L [16]. Diseases like dental and skeletal fluorosis can be caused by fluoride concentration of 3 mg/L or more [17].

Previous studies in countries like Finland, Jordan, the USA, and Sweden [18–22] have shown very high uranium concentration in groundwater. In contrast, countries such as Argentina, Canada, Italy, Kuwait, South Greenland [19, 23–26] have shown relatively low uranium concentration. In India, too, several studies have been executed to estimate the groundwater uranium concentration. Higher concentrations are reported from places like Kolar (Karnataka) [27], southwest Punjab and Bhatinda (Punjab) [8, 28], Peddagattu and Seripally (Andhra Pradesh) [29], Hyderabad (Telangana) [30], Sirsa (Haryana) [5], Madurai, Tamil Nadu [31] and Central Tamil Nadu [32]. On the other hand, studies carried out in places like Vishakhapatnam (Andhra Pradesh) [33], Jaduguda (Jharkhand) [1], Nadia (West Bengal) [34], and Patna (Bihar) [2] have estimated a lower concentration of uranium in groundwater. The uranium concentration in groundwater is also observed changing with seasons, as reported from India's different places [35–37]. Due to other heavy metals and major ions present in the groundwater, human health hazard risk has also been recorded [38–43].

In the state of Assam, only a few studies have been performed. A study carried out in the state capital city Guwahati reported a relatively lower uranium concentration in the groundwater [44]. On the other hand, in Karbi Anglong district, uranium concentration higher than that of the WHO permissible limit (with a maximum value of 1.47–10.66 mg/L) in soil samples has been recorded by Kakati et al. [45]. It is, therefore, crucial to analyse the uranium concentration in groundwater of Assam, including

the Nalbari district, as no study has been attempted to the best of our knowledge.

Considering the aspects mentioned above, particularly toxicity caused by uranium, the objective of the present work is to evaluate the concentration of uranium in the groundwater, which is primarily used for drinking. The study also estimates the radiation dose for different age groups and the carcinogenic and non-carcinogenic risk to the district's inhabitants, which may arise due to the consumption of water contaminated with uranium. Fourteen other physico-chemical parameters were also monitored to study the correlation with the analysed uranium concentration, if any. This study is expected to provide the baseline data on uranium present in the study area's groundwater.

2 Materials and method

2.1 Study area

Nalbari district is one among 33 Districts of state Assam, India. It is located 51 km south towards the state capital Dispur at latitudes between 26°10'N and 26°47'N and 91°15'E and 91°38'E longitudes. It shares a border with Baksa district to the north, district of Kamrup to the south and east, and Barpeta on the west. Nalbari district occupies approximately 2257 km² of area. The elevation of the district is in the range from 79 to 46 meters. The Nalbari district is located at the plains of Brahmaputra valley. The Brahmaputra's tributaries like Pagladiya, Nona, Buradia, Borolia, Tihu, etc., are wild, which causes floods in the area. These tributaries originate from the foothills of the Himalayas and flow into the Brahmaputra towards the southern part of the district.

Physiographically, the Nalbari district has two major regions, the northern alluvial region where the soil is deep reddish clayey alluvial soil, and southern flood plains of Brahmaputra river where recent age alluvial soil can be seen [46, 47]. A gentle slope can be observed from north to south towards the Brahmaputra. Throughout the district, the entire area is occupied by alluvial sediments of clay, sand, silt, boulders, and gravel of quartz, feldspars. The groundwater can be found in a semi-confined state, which belongs to a mono aquifer system. The depth of the system varies from 40 to 250m. The water level is almost directly dependent upon the area's total precipitation level in the aquifer system. The topmost thick alluvial layer of the ground has uniform porosity, and the permeability is observed to be in the range of 10–15% [46, 48]. A total of 68% of the district's land area is used for agricultural purposes; forest covers 3%, and other areas, including wasteland. The cultivable area covers 28.5%, and less than

0.5% of the land is used for industrial purposes. The district comprises rural areas where villages are right next to the agricultural lands [46, 48]. The climate of Nalbari is sub-tropical with semi-dry hot summer and cold winter. The humidity of the district hovers around 80%. From May to August, heavy rainfall occurs for which the people of the area experiences flood. Nalbari experiences annual average rainfall of about 1500 mm.

2.2 Collection and preservation of samples

A total of 31 samples were collected from different sources of the area based on a grid map of grid size $6 \times 5 \text{ km}^2$. The sampling locations are shown in Fig. 1 by numbers. The collection was done from tube-wells, wells, and local water supply reservoirs. A total of 28 samples were taken from tube-wells. The average borehole depth of tube-wells was around 18m. Two samples were taken from local water supply reservoirs; the water supply system's average borehole depth is 95m. In this case, we have collected the sample from the reservoirs, not from a household tap. A single sample is taken from a concrete well with a

depth of around 15m. Sampling was done in the year of 2016; in the pre-monsoon samples collection was done in the month of May, and in the post-monsoon, the same has been done in October. A $0.45 \mu\text{m}$ membrane filtration system was used for the filtration of samples before analysis. From every source, groundwater was collected in two separate containers, one for the investigation of general parameters and the other for uranium analysis. To prevent wall adsorption and slower biological changes, 2 ml concentration HNO_3 was added to 1 L sample to analyse uranium concentration.

2.3 Estimation of Uranium in samples

Uranium analysis was done in LF-2a LED fluorimeter (Quantalase Enterprises Pvt. Ltd., India). The calibration was done using a standard uranium solution of 1, 2, 5, 10, 15, 20, and $30 \mu\text{g/L}$ provided by the manufacturer. An internal standard addition method was used during analysis to prevent organic and inorganic interference present in the samples. 5% sodium pyrophosphate solution was prepared and acidified with orthophosphoric

Fig. 1 Location map of the area of survey (Nalbari district) representing the sampling location by numbers

acid dropwise to adjust the pH range within 6.5–7.5. Further to convert different uranium species into a single form having identical fluorescence is done by adding fluorescent enhancing agents like sodium pyrophosphate to the sample. To refrain errors in pipetting, analytical balance and micropipettes were used. The limit of detection obtained using this method was 0.2 µg/L. Each sample was effectively analysed four times ($n = 4$). Statistical analyses included calculations of the mean and median value was calculated using Microsoft Excel software.

2.4 Estimation of Physico-chemical parameters in groundwater samples

The measurement of pH, TDS, EC (electrical conductivity), ORP was done using a portable electrode-based multiparameter kit. EDTA complexometric titration method was employed to determine the total hardness and calcium in the groundwater samples. Hence the hardness of magnesium is simply the difference between the values of total hardness and calcium hardness. The total alkalinity was found by the H_2SO_4 titration method using methyl orange as an indicator, which was due to bicarbonate alkalinity only. $AgNO_3$ in the presence of the K_2CrO_4 indicator in Mohr's method, gives reddish-brown precipitation of $AgCl$, which has been used for chloride estimation. The phosphate, nitrate, and sulphate concentrations were determined respectively by the stannous chloride method, screening method, and turbidimetric method. The fluoride concentration was measured using colorimetrically with SPADNS reagent. A UV-Visible spectrophotometer (Hitachi 3210) was used for the above techniques. American Public Health Association (APHA) standard protocols have been followed in the analysis of all the parameters [49].

2.5 Radiation dose evaluation for various age groups

The net annual effective dose of radiation (D_R) for various age groups due to consumption of drinking water was estimated using the equation given below [50],

$$D_R = A_U \times DWI \times 365 \times FDC \quad (1)$$

A_U = Activity concentration of uranium (Bq/L). Unit conversion factor, $1 \mu g/L = 2.528 \times 10^{-2} Bq/L$ was used to calculate the value of A_U . $DWI = DRI$ s [51] prescribed daily water intake rate for various age groups (L/day), $FDC = IAEA$ [52] suggested factor of dose conversion for definite age groups (Sv/Bq).

2.6 Carcinogenic risk assessment

USEPA approved equations (Equations 2 and 3) [53] were used to evaluate the excess cancer risk (ECR),

$$ECR = A_U \times R_F \quad (2)$$

$$R_F = r \times C_R \times E_p \quad (3)$$

Where R_F = risk factor (L/Bq), r = risk coefficient value for uranium mortality, $1.13 \times 10^{-9} Bq^{-1}$, C_R = consumption rate of water (L/day), E_p = period of exposure. For adults, $C_R = 4.05$ L/day [8] and $E_p = 23725$ days. For children, $C_R = 2$ L/day [11] and $E_p = 3650$ days [54].

2.7 Non-carcinogenic risk assessment

Hazard quotient (H_Q) is used to express the non-carcinogenic risk. The ratio of lifetime average daily dose (LADD) and the reference dose (R_fD) gives the net H_Q . The value of R_fD is 4.53 µg/kg/day. Any H_Q value of less than 1 is regarded as safe from chemical toxicity point of view [55].

$$H_Q = \frac{LADD}{R_fD} \quad (4)$$

$$LADD = \frac{C_U \times C_R \times F_E \times D_E}{E_L \times W_B \times 365} \quad (5)$$

Where C_U = uranium concentration (µg/L), C_R = consumption rate of water (L/day), F_E = frequency of exposure (~350 days per year) [53], D_E = duration of total exposure (years), E_L = expectancy of life (years), W_B = body weight (kg).

Therefore, using the value of $C_R = 4.05$ L/day, $D_E = 65$ years [11], $E_L = 65$ years, $W_B = 53$ kg [56] (for adults) and $C_R = 2$ L/day, $D_E = 10$ years, $E_L = 10$ years, $W_B = 32.7$ kg (for children) [54].

3 Results and discussions

3.1 Estimation of uranium and other water quality parameters

In Table 1, the statistical summary of uranium and other water quality parameters of pre-monsoon and post-monsoon samples of the Nalbari district was reported. The uranium concentration in groundwater is found to be 0.3–7.1 µg/L and 0.6–10.3 µg/L in the pre-monsoon and post-monsoon, respectively. The comparatively higher uranium concentration in post-monsoon may be attributed to uranium dissolution from soil sediments in the

Table 1 Statistical summary of the water quality parameters and its comparison with WHO standards

Water quality parameters	WHO (2011) Permissible limit	Pre-monsoon					Post-monsoon				
		Min	Max	Mean	Median	No. of samples above the permissible limit	Min	Max	Mean	Median	No. of samples above the permissible limit
pH	6.5–8.5	6.1	7.3	6.7	6.7	–	6.4	7.5	6.8	6.8	–
EC ($\mu\text{S}/\text{cm}$)	–	80	560	245	230	–	90	634	239	240	–
TDS (mg/L)	1000	40	370	164	160	–	67	410	172	160	–
Salinity (mg/L)	–	60	420	183	173	–	68	476	180	180	–
ORP (mV)	550	–27	68	26	23	–	–31	23	11	19	–
Total Hardness (mg/L)	300	40	151	88	82	–	58	175	83	81	–
Calcium (mg/L)	100 ^b	29	124	66	61	1	52	139	62	60	1
Magnesium (mg/L)	50 ^b	6	52	22	20	1	7	36	21	21	–
Total Alkalinity (mg/L)	300	64	126	83	80	–	68	144	88	85	–
Chloride (mg/L)	250	8	46	17	13	–	15	48	21	18	–
Fluoride (mg/L)	1.5	0.02	0.70	0.26	0.28	–	0.14	0.82	0.36	0.36	–
Nitrate (mg/L)	50	5.8	56.7	16.0	14.1	1	7.7	68.3	20.6	19.5	2
Sulphate (mg/L)	500	2.9	15.4	7.93	7.10	–	8.3	28.3	11.2	10.8	–
Phosphate (mg/L)	–	0.01	0.63	0.09	0.05	–	0.04	0.54	0.12	0.07	–
Uranium ($\mu\text{g}/\text{L}$)	30	0.3	7.1	2.15	2.40	–	0.6	10.3	2.75	2.8	–

^aMin= Minimum, Max= Maximum^bWHO (2004, 2006)[57, 58]

Fig. 2 Pre-monsoon and post-monsoon seasonal variation of uranium

rainy season (Fig. 2). The maximum concentration 10.3 µg/L was found in the sample collected from Bhunukuchi under Barkhetri block (lat: 26°25′44″, long: 91°29′06.9″; sampling point number 12 in the study area map, Fig. 1) in post-monsoon. The variation observed in the uranium concentration may be due to the different geographical locations with different meteorological phenomena. All samples of the study area show uranium concentration well under the WHO prescribed limit of 30 µg/L during both seasons.

The ORP of the samples was found in the range of (–27)–68 mV in the pre-monsoon season, whereas (–31)–23 mV in post-monsoon, respectively. The total hardness recorded for the samples in both the seasons was found within the permissible limit. The total hardness varied from 40 to 151 mg/L in pre-monsoon and 58–175 mg/L in post-monsoon. The calcium concentration varied from 29 to 124 mg/L and 52–139 mg/L in pre-monsoon and post-monsoon, respectively. One sample, each from pre and post-monsoon, exceeded the WHO safe limit (100 mg/L) of calcium concentration. The concentration of magnesium was observed between 6 and 52 mg/L in pre-monsoon and 7–36 mg/L in post-monsoon. The evaporation effect of water in the pre-monsoon season for which the number of ions increases in groundwater may be held responsible for the greater values of hardness and magnesium and calcium concentration. The samples' total alkalinity ranged from 64 to 126 mg/L and 68–144 mg/L during pre-monsoon and post-monsoon season. The chloride ion concentration was observed to vary in the range of 8–46 mg/L in pre-monsoon, and 15–48 mg/L in post-monsoon; both the ranges were within the WHO prescribed limit of 250 mg/L [11]. A moderately high nitrate concentration was recorded in the water samples with the range of 5.8–56.7 mg/L and 7.7–68.3 mg/L in pre-monsoon and post-monsoon, respectively. This reasonably high nitrate concentration may be attributed to

the region's agricultural practices as agricultural lands primarily cover the study area. The fluoride concentration was also found within the safe limit of 1.5 mg/L. The concentration of sulphate varied from 2.9 to 15.4 mg/L in pre-monsoon and 8.3–28.3 mg/L in the post-monsoon season. The phosphate concentration in pre-monsoon was found to be 0.01–0.63 mg/L, and in post-monsoon, the same was 0.04–0.54 mg/L.

3.2 Correlation analysis

Pearson's correlation matrix was done for 15 sets of variables and stated in Table 2a and b for both the seasons. A significant positive correlation of phosphate with uranium present in the region's groundwater may be accredited to the agricultural practices done here. It can be summarized that heavy usage of chemical fertilizers in the paddy fields enhances the leaching of phosphate through the soil, which then precipitates as $\text{UO}_2(\text{HPO}_4)_2^{2-}$ [59] in the groundwater. It is reported that phosphate fertilizers contain natural radioactivity and are a credible uranium source in the environment [60–62]. Nitrate holds a mild but crucial positive correlation with uranium in both seasons. In addition to this, a good positive correlation of nitrate with TDS is observed. This finding suggests that nitrate may take part an important role in the dissolution of uranium from minerals like uranyl nitrate ($\text{UO}_2(\text{NO}_3)_2$) [34, 63]. Hence it can be said that agricultural nitrate and phosphate fertilization might be the carrier of uranium. This region of Assam is well known for rice cultivation since rice is the most widely consumed food crop in Assam. Therefore, extensive use of fertilizers such as urea, ammonium sulphate, NPK in the agricultural lands might be another reason for uranium in the groundwater of the region. Uranium exhibits a positive correlation with ORP, which

Table 2 Pearson's correlation matrix for uranium and other water quality parameters in pre-monsoon ($n=31$)

a	U	pH	EC	TDS	#Sal	ORP	TH	Ca	Mg	TA	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	PO ₄ ³⁻
U	1														
pH	-0.29	1													
EC	-0.17	*0.55	1												
TDS	-0.17	0.58	0.98	1											
#Sal	-0.17	0.55	1.00	0.98	1										
ORP	0.53	-0.76	-0.55	-0.57	-0.55	1									
TH	-0.36	0.42	0.78	0.74	0.78	-0.45	1								
Ca	-0.33	0.40	0.75	0.71	0.75	-0.41	0.96	1							
Mg	-0.34	0.39	0.64	0.63	0.64	-0.44	0.83	0.65	1						
TA	0.10	0.40	0.73	0.69	0.73	-0.30	0.58	0.54	0.53	1					
F ⁻	-0.15	-0.45	-0.25	-0.23	-0.25	0.23	-0.07	-0.12	0.05	-0.22	1				
Cl ⁻	-0.20	0.06	0.62	0.57	0.62	-0.18	0.50	0.51	0.34	0.33	-0.08	1			
NO ₃ ⁻	0.20	0.29	0.50	0.49	0.50	-0.28	0.37	0.34	0.35	0.46	-0.31	0.25	1		
SO ₄ ²⁻	0.27	0.12	0.56	0.56	0.56	-0.12	0.53	0.54	0.37	0.41	-0.20	0.23	0.68	1	
PO ₄ ³⁻	0.46	0.05	0.18	0.23	0.18	0.13	-0.07	-0.11	0.03	0.13	-0.13	-0.18	0.07	0.36	1
b	U	pH	EC	TDS	#Sal	ORP	TH	Ca	Mg	TA	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻	PO ₄ ³⁻
U	1														
pH	-0.14	1													
EC	0.02	0.34	1												
TDS	0.10	0.31	0.96	1											
#Sal	0.02	0.34	1.00	0.96	1										
ORP	0.22	-0.86	-0.22	-0.17	-0.22	1									
TH	-0.06	-0.07	0.35	0.37	0.35	0.02	1								
Ca	-0.09	-0.20	0.18	0.20	0.18	0.09	0.94	1							
Mg	0.03	0.23	0.55	0.56	0.55	-0.12	0.72	0.44	1						
TA	0.11	0.04	0.64	0.63	0.64	-0.05	0.43	0.32	0.47	1					
F ⁻	-0.10	-0.26	-0.33	-0.23	-0.33	0.18	-0.14	-0.08	-0.20	-0.06	1				
Cl ⁻	0.01	-0.12	0.55	0.56	0.55	0.03	0.67	0.61	0.53	0.55	-0.08	1			
NO ₃ ⁻	0.35	-0.02	0.43	0.42	0.43	0.01	0.10	-0.01	0.25	0.64	-0.21	0.29	1		
SO ₄ ²⁻	0.25	0.04	0.66	0.55	0.66	-0.05	0.07	-0.02	0.21	0.62	-0.20	0.43	0.71	1	
PO ₄ ³⁻	0.51	-0.11	0.07	0.17	0.07	0.24	-0.11	-0.09	-0.09	-0.08	0.13	-0.08	0.02	0.20	1

*The positive correlation values (p-value < 0.05) were highlighted in bold

#Sal = Salinity

signifies the favourable condition for uranium transport and release in aquifers [2, 64, 65]. A minor but positive correlation of sulphate with uranium suggests that SO₄²⁻ ions may be an additional complexing agent for uranyl (UO₂²⁺) ions in groundwater [34, 66, 67]. Sulphate shows a strong positive correlation with EC, TDS, total hardness, calcium, total alkalinity, chloride, and nitrate, which confers the parameters' interdependency. A good positive correlation of chloride with total alkalinity, EC, TDS, calcium, magnesium, and total hardness has also

been observed. Similarly, a good positive correlation for magnesium is also noticed with total alkalinity, EC, TDS, total hardness, and calcium. Therefore, the magnesium ions largely influence the ionic conductance of the groundwater of the study area.

3.3 Radiation dose evaluation of uranium for various age groups

The age-dependent net annual dose of uranium was calculated and given in Table 3. The higher dose values in the

Table 3 Age-dependent annual effective dose of uranium ($\mu\text{Sv/y}$) due to ingestion of groundwater

Gender and stage of life	Age group (in years)	DWI (L/day)	The annual effective dose of uranium ($\mu\text{Sv/y}$)					
			Pre-monsoon			Post-monsoon		
			Min	Max	Mean	Min	Max	Mean
Infants	0–0.5	0.7	0.66	15.59	4.73	1.32	22.62	6.03
	0.6–1	0.8	0.75	17.82	5.41	1.51	25.85	6.89
Children	1–3	1.3	0.43	10.22	3.10	0.86	14.83	3.95
	4–8	1.7	0.38	8.91	2.70	0.75	12.93	3.44
Males	9–13	2.4	0.45	10.69	3.25	0.90	15.51	4.13
	14–18	3.3	0.61	14.48	4.40	1.22	21.01	5.60
	Above 18	3.7	0.46	10.91	3.31	0.92	15.82	4.22
Females	9–13	2.1	0.40	9.36	2.84	0.79	13.57	3.62
	14–18	2.3	0.43	10.10	3.06	0.85	14.65	3.90
	Above 18	2.7	0.34	7.96	2.42	0.67	11.55	3.08
Pregnancy	14–18	3.0	0.56	13.17	4.00	1.11	19.10	5.09
Lactation	19–50	3.0	0.37	8.84	2.68	0.75	12.83	3.42
	14–18	3.8	0.70	16.68	5.06	1.41	24.20	6.45
	19–50	3.8	0.47	11.20	3.40	0.95	16.25	4.33

case of 0.6–1 years old compared to 0–0.5 years infants may be accredited to a higher water consumption rate of 0.6–1 years old group. Though infants consume less water than adults, the annual dose for infants is more compared to adults because of the difference of smaller organ weights and their metabolism, resulting in higher radiosensitivity [3]. During pregnancy and lactation periods, females receive a higher radiation dose, which may be attributed to increased water intake. However, all males show a higher radiation dose as compared to females. The higher amount of water intake by males may be the reason for this. The annual effective dose of all life stage groups was within the recommended level of $100 \mu\text{Sv/y}$ by WHO [11].

3.4 Assessment of carcinogenic risk

The excess cancer risk (ECR) was computed and outlined in Table 4. For children, the ECR was ranged between 0.006×10^{-5} and 0.148×10^{-5} in pre-monsoon and 0.013×10^{-5} and 0.215×10^{-5} in the post-monsoon season.

For adults, in pre-monsoon ECR varied from 0.082×10^{-5} to 1.949×10^{-5} with the mean value of 0.592×10^{-5} and in post-monsoon 0.165×10^{-5} – 2.827×10^{-5} with the mean value of 0.754×10^{-5} respectively. The ECR values for both children and adults during both seasons were low compared to the AERB prescribed limit of 1.67×10^{-4} [55]. Based on the maximum groundwater uranium concentration, it can be summarized from Table 4 that there could be 2–3 cases of cancer per one hundred thousand adult population on continuous uranium exposure.

3.5 Assessment of non-carcinogenic risk

The LADD values and H_Q were evaluated and reported in Table 4. LADD values for children ranged from 0.018 to $0.416 \mu\text{g/kg/day}$ in pre-monsoon and 0.03 – $0.604 \mu\text{g/kg/day}$ in post-monsoon. For adults, in pre-monsoon LADD values ranged between 0.022 and $0.520 \mu\text{g/kg/day}$ and in post-monsoon 0.044 – $0.755 \mu\text{g/kg/day}$. According to WHO [11], the prescribed limit of LADD is $1 \mu\text{g/kg/day}$. The H_Q values for children in both seasons varied from 0.004 to

Table 4 Carcinogenic and non-carcinogenic risk in pre-monsoon and post-monsoon

Parameters		ECR=Excess Cancer Risk (10^{-5}) ECR=Excess Cancer Risk (10^{-5})			LADD = Lifetime Average Daily Dose ($\mu\text{g/kg/day}$)			H_Q = Hazard Quotient		
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Pre-monsoon	Children	0.006	0.148	0.045	0.018	0.416	0.126	0.004	0.092	0.028
	Adults	0.082	1.949	0.592	0.022	0.52	0.158	0.005	0.115	0.035
Post-monsoon	Children	0.013	0.215	0.057	0.035	0.604	0.161	0.008	0.133	0.036
	Adults	0.165	2.827	0.754	0.044	0.755	0.201	0.011	0.167	0.044

0.092 and 0.008–0.133, with the mean value of 0.028 and 0.036. For adults, H_Q ranged from 0.005 to 0.115 with mean value of 0.035 and 0.011–0.167 with mean value of 0.044, respectively. Therefore, the H_Q values for all the samples in both seasons were less than the AERB recommended limit of 1 [55], and hence the water is safe from the chemical toxicity effect.

3.6 Comparison of uranium concentration with previous studies

The uranium concentration obtained from the previously reported studies in different states of India and worldwide is compared with the present study and shown in Table 5a and b. Uranium concentration in groundwater worldwide shows large variations. In Vishakhapatnam, Bhangare et al. recorded a uranium concentration of 0.6–12.3 µg/L [33].

Patra et al. reported that, around the uranium mining sites in Jaduguda, Jharkhand, the concentration of uranium ranged from 0.03 to 11.6 µg/L [1]. In Nadia, West Bengal, uranium concentration ranged from 0.21 to 20.9 µg/L in groundwater samples, reported by Das et al. [34]. Similarly, a uranium concentration of 0.1–14.5 µg/L was found in drinking water samples in Patna, Bihar, reported by Kumar et al. [2]. All the studies mentioned above obtained low uranium concentration values under the WHO limit of 30 µg/L [11] and found comparable with the present study. Similarly, lower values were observed for Guwahati, Assam (0.08–5.32 µg/L), reported by Talukdar et al. (1983) [44].

However, higher uranium concentration has been reported in southwest Punjab (0.5–579 µg/L) [8], Kolar, Karnataka (0.3–1442.9 µg/L) [27], Bhatinda, Punjab (11.7–113.7 µg/L) [28], Peddagattu/Seripally, Andhra Pradesh (0.6–521.15 µg/L) [29], Gaya, Bihar (0.1–238.2 µg/L)

Table 5 Reported uranium concentration in groundwater from (a) Indian states and (b) worldwide

a		
Indian cities/states	Uranium concentration (µg/L)	References
Kolar, Karnataka	0.3–1442.9	[27]
Southwest Punjab	0.5–579	[8]
Bhatinda, Punjab	11.7–113.7	[28]
Peddagattu/Seripally, AP	0.6–521.15	[29]
Gaya, Bihar	0.1–238.2	[6]
Hyderabad, Telangana	0.6–82	[30]
Sirsa, Haryana	0.93–290	[5]
Madurai, Tamil Nadu	0.2–156.84	[31]
Central Tamil Nadu	0.79–71.93	[32]
Vishakhapatnam, AP	0.6–12.3	[33]
Jaduguda, Jharkhand	0.03–11.6	[1]
Nadia, West Bengal	0.21–20.9	[34]
Patna, Bihar	0.1–14.5	[2]
Guwahati, Assam	0.08–5.32	[44]
Nalbari, Assam, Northeast		
India	0.3–7.1 (Pre-monsoon) 0.6–10.3 (Post-monsoon)	Present Study
b		
Different country worldwide	Uranium concentration (µg/L)	References
Southern Finland	6–3400	[18]
Finland	0.02–6000	[19]
Jordan	0.04–1400	[20]
USA	0.02–652	[21]
Sweden	<0.2–470	[22]
Argentina	0.04–11.0	[23]
Ontario, Canada	0.05–4.21	[24]
Italy	0.02–5.2	[19]
Kuwait	0.02–2.48	[25]
South Greenland	0.5–1.0	[26]

[6], Madurai, Tamil Nadu (0.2–156.84 µg/L) [31], Central Tamil Nadu (0.79–71.93 µg/L) [32]. Further, in other countries like Argentina (0.04–11.0 µg/L) [23], Ontario, Canada (0.05–4.21 µg/L) [24], Italy (0.02–5.2 µg/L) [19], Kuwait (0.02–2.48 µg/L) [25], South Greenland (0.5–1.0 µg/L) [26] has been reported concentration of uranium in lower side and found comparable with the current study. From the comparison with the previous studies as discussed above, the uranium concentrations in Nalbari, Assam is on the very lower side.

4 Conclusions

The range of concentration of uranium in groundwater observed in the present study was considerably lower than the WHO permissible value of 30 µg/L. The concentration is also observed to change with seasons and is found to be higher in post-monsoon. The disbandment of uranium in groundwater from soil sediments during the rainy season may hold responsible for the same. Uranium exhibits a positive correlation with phosphate, nitrate, and sulphate in both seasons, which may be due to the region's different agricultural activities. So, it is needful to mention that in the future, nitrate, sulphate, and phosphate concentration in groundwater may exacerbate uranium dissolution in the study area as they are good carriers of uranium. Correlation study shows that parameters are less or more correlated with each other, which implies the ions' interdependence in the groundwater system of the region. Similarly, the annual effective dose was also recorded within the WHO safe limit of 100 µSv/y for all the different age groups. The carcinogenic and non-carcinogenic risk due to water consumption was much lesser than the permissible limits for both children and adults. Hence, the water can be considered to be safe for use. The study indicates that the drinking water around the Nalbari district of Assam does not need any attention from the policymakers regarding uranium and other minerals. It appears instructive to regularly monitor uranium to determine alterations in uranium in Assam's groundwater for a unique variation.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest

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