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Poojashri Ravindra Naik[1], Vinod Alurdoddi Rajashekara[2], Rajalakshmi Mudbidre[3]

Estimation of Natural Uranium and Its Risk-Assessment in Groundwater of Bangalore Urban District of Karnataka, India

Abstract: In this study, 56 groundwater samples were taken from diverse sources in Bangalore Urban district during the pre-monsoon and post-monsoon seasons to measure the uranium concentration and its correlation with different water-quality parameters. The uranium concentration varied from 0.94–98.79 μg/L during the pre-monsoon season and from 1.38–96.52 μg/L during the post-monsoon season. Except for a few readings, all were within the safe limit of 60 μg/L as prescribed by India's Atomic Energy Regulatory Board (AERB), Department of Atomic Energy (DAE). Owing to its slightly higher concentration, a study on the radiological and chemical risks that are caused due to the ingestion of uranium was assessed. Based on the radiological aspect, cancer mortality and its risks were assessed, wherein all of the samples were well within the acceptable limit of 10^{-4}; therefore, consuming these water samples was radiologically safe. However, when the risk that was caused by chemical toxicity was assessed, a few samples exceeded the hazard quotient (HQ) value of more than 1, thus illustrating that individuals were vulnerable to chemical risk. This paper features assessments of uranium and its risks to public health in groundwater samples if it exceeded the safe limit. Additionally, it recognizes the value of periodically assessing and treating the area's drinking water sources.

Keywords: groundwater, Bangalore Urban district, uranium, correlation, risk-assessment

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[1] R V College of Engineering, Department of Civil Engineering, Bengaluru, India; Visvesvaraya Technological University, Belagavi, India, email: poojanaik22@gmail.com (corresponding author), https://orcid.org/0009-0000-6274-8004

[2] R V College of Engineering, Department of Civil Engineering, Bengaluru, India, email: vinodar@rvce.edu.in, https://orcid.org/0000-0003-4333-8813

[3] R V College of Engineering, Department of Chemical Engineering, Bengaluru, India, email: rajalakshmim@rvce.edu.in, https://orcid.org/0000-0002-9503-4216

1. Introduction

Earth's crust contains uranium (U) – a primordial radionuclide. In nature, U exists as a rare radioactive heavy metal. Its natural distribution varies from rock-like structures to mineral deposits of various forms [1]. It is found as an oxide (UO_2^{2+} – uranyl) in its most stable oxidation state (VI) in groundwater. It is the most long-living radionuclide, which produces ions with +4 (UO_2 and U^{4+}) and +6 (UO_3 and UO_2^{2+}) oxidation states, of which U (+6) (the uranyl (UO_2^{2+}) ion – uranium oxide) reportedly has a higher solubility and the ability to form stable complexes with a variety of organic and inorganic ligands [2]. Since uranium is a naturally occurring lithophilic element in groundwater, its level in groundwater is dependent on the local lithology, geomorphology, and other geological factors [3]. The occurrence and distribution of uranyl species in surface and subsurface water are controlled by the redox condition, pH, and CO_2 partial pressure [4, 5]. As U (+6) as a uranyl (UO_2^{2+}) compound is more soluble, it enters and contaminates groundwater by leaching from rock structures. Meanwhile, the use of uranium-containing pesticides and insecticides on land result in surface water contamination [6, 7]. Due to leaching, the components of uranium that are present in pesticides/insecticides may reach groundwater by contaminating it with uranium [8]. Adding to this, various anthropogenic sources such as mining could also contribute to high uranium concentrations in groundwater [9, 10].

There have also been reports of uranium contamination in drinking water from a few researchers worldwide. According to studies by Drury et al. [11], the ranges of the uranium content in the studied U.S. drinking water were 0.01–652, 0.11–640, and 0.02–6.99 μg/L, respectively [11, 12]. Similarly, surface water in Ohio (USA), Datong Basin (China), and Singai (Egypt – uranium mineralized) witnessed uranium concentrations of 0.3–3.9, 1.2–16, and 600–1130 μg/L, respectively [13]. Ribrira da Parithana of Portugal recorded a uranium concentration of 7.7–48.6 μg/L [14], and the rivers of China recorded concentrations that ranged 3.85–7.57 μg/L [15].

Groundwater has been discovered to contain higher levels of naturally occurring uranium in smaller geographic areas around India. Major uranium discoveries in India have occurred at Jaduguda (Jharkhand); there have also been occurrences of uranium found in the Cuddapah basin of Andhra Pradesh [16]. These include Lambapur-Peddagattu, Chitrial, Kuppunuru, Tumallapalle, and Rachakuntapalle, which have contributed significantly toward the uranium reserve base of India [17]. Other states like Rajasthan, Karnataka, and Chhattisgarh also have some major deposits of uranium.

The AERB (Atomic Energy Regulatory Board, Department of Atomic Energy, 2004) strictly regards a uranium concentration of 60 μg/L as a safe limit in drinking water. To determine the uranium content in various locations in India, numerous researchers have undertaken investigations. In line with this, Sandeep et al. reported uranium concentrations of 6.37 and 43.31 μg/L in the Bhiwani and Sirsa districts of Western Haryana, respectively [18]. Eastern Harayana reported uranium

concentrations that varied from 9.1 to 155.1 μg/L [19]. Sharma and Singh [20] revealed uranium concentrations that varied from 0.13 to 1340 μg/L in the Mansa district of the Malwa region. Almost 81% of their samples exceeded the guideline value of 60 μg/L (as prescribed by the AERB). Santosh et al. carried out studies in the Durg district of Jharkhand, which witnessed a maximum uranium concentration of 45.7 μg/L [21]. Kedar (Mandakini) Valley of Uttarkhand, Bagjata of Jharkhand, and the Rajnandgaon district of Chattisgarh witnessed varying uranium concentrations of 0.02–63.7, 0.5–11.2, and 0.5–99.0 μg/L, respectively. Meher et al. [22] reported an average uranium concentration of 2.75 μg/L in the Alakananda River and 1.86 μg/L at the River Ganga. Kashyap and Ghosh [23] mentioned concentrations of 0.031 to 140.1 μg/L in the Korba district, Chhatisgarh. The Bagjata and Banduhurang districts of Jharkhand witnessed concentrations of 0.5–11.2 and 0.5–27.5 μg/L, respectively [8, 21].

The southern region of India has been the subject of numerous inquiries. Central Tamil Nadu reported uranium concentrations of 11.78–68.28 μg/L, which was due to the dominance of lithological granitic structures like granite, quartzite, fissile hornblende, biotite, and gneiss [22, 23]. The Palakkad, Thrissur, Kottayam, and Ernakulam districts of Kerala witnessed 0.5–12.54 μg/L uranium concentrations [24], whereas salem district of tamil nadu and central part of tamil nadu was reported with 0.01–385.40 μg/L and 0.4–68.28 μg/L respectively [25, 26]. The Nalgonda district, Vishakaptanam, and Tummalapalle of Andhra Pradesh have been reported to have varying uranium concentrations of uranium (0.2–68.0, 0.6–12.3, and 0.38–79.70 μg/L, respectively). From the above results that were reported in different parts of India, it can be presumed that groundwater is used as the sources of drinking water by 40% of the population in most locations. People residing in urban areas consume water with prior treatment; hence, the size of the exposed population is small. On the other hand, people residing in the rural areas depend on groundwater more often in the form of community or individual wells for drinking and agricultural purposes. Stating varying concentrations of uranium in different parts of India, it can be observed that the residents rely on groundwater from basement aquifers for drinking water supplies as well as domestic and agricultural use. So, it is a significant concern to assess elevated levels of uranium concentrations that are being exposed to the public [27].

When the public is exposed to elevated levels of uranium concentrations, it leads to health risks because of its chemical and radiological toxicity. The route of the exposure, the solubility of the particles, the contact time, and the method of the disposal are the main grounds for uranium morbidity. The uranium content and its mobility are controlled by pH, ORP (oxidation and reduction potential) and, complexing agents such as sulfates, fluorides, phosphates, carbonates, etc. in fluid systems [28, 29]. The presence of U (VI) in water (either ground or surface) has garnered significant attention; when someone is exposed to high levels of uranium, it could damage their kidneys and cause nephritis. Moreover, intakes of U above 60 ppb is known to cause acute kidney failure and is carcinogenic to human health [30, 31].

Considering the significance of determining uranium concentrations in the context of their impact on human health and the environment, an effort has been made in the current work to estimate the concentrations of uranium (U) in groundwater sources during the pre-monsoon (PRM) and post-monsoon (POM) season of the Bangalore Urban district, study its correlation with water-quality parameters, and estimate the radiological and chemical risks that can be attributed to uranium ingestion.

2. Geology of Study Area

The Bangalore Urban district is the most populous district in the Indian state of Karnataka, which is spread across 2174 km^2 and is located between the north latitudes of 12°39′32′′ and 13°14′13′′ and the east longitudes of 77°19′44′′ and 77°50′13′′; it is located on the Deccan plateau at a height of more than 900 m (3000 ft) above sea level. The Bangalore Urban district is surrounded by the Bangalore Rural district to the east and north, the Ramanagara District to the west, and the Krishnagiri District of Tamil Nadu to the south. The Bangalore Urban district has four taluks; i.e., Bangalore North, Bangalore South, Bangalore East, and Anekal Taluk (Fig. 1). The dominant rock structures that are spread across the Bangalore Urban District are granites, gneisses, and the peninsular gneissic complex (PGC) that is associated with Closepet and other granitic rocks (Fig. 2). The dominant soil types are red laterite, argillaceous, and from fine loamy to clay-like.

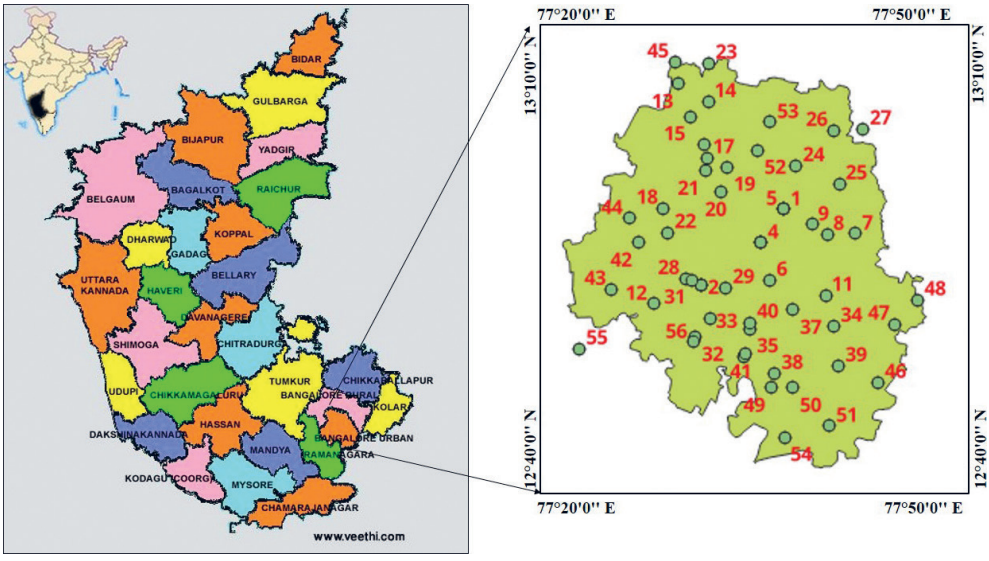

Fig. 1. Map of Karnataka and locations of sampling sites

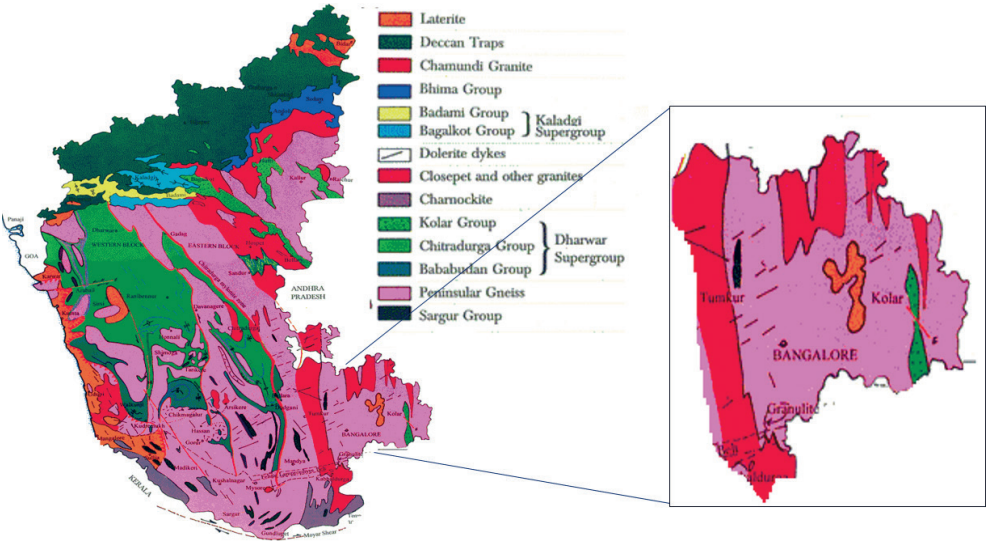

Fig. 2. Geology of Karnataka map
Data source: Department of Mines and Geology, Government of India

The Arkavathi River Basin, which makes up 46% of the district, is to the west. The Dakshina Pinakini River Basin, which makes up 54% of the district, is to the east. Numerous elements, including the fracture pattern, level of weathering, geomorphological configuration, and rainfall amount, influence groundwater circulation and the recharging of the aquifers. The resistivity tests revealed the existence of weathered (permeable) rock that extend down to a depth of 30 m. The major aquifer is located at a depth of 25–30 m. Even below 60 m, there are still aquifers [32, 33].

The study region is situated on the tonalitic biotite gneisses-dominated Archean gneiss complex of Peninsular India. Along with a few tanks and lift-irrigation schemes, groundwater is the district's main source of irrigation water [34]. The two main crops that are farmed in the district are paddy and ragi, and the supporting crops including maize, cereals, and groundnuts. The Precambrian migmatite, granodiorite, tonalite, and gneiss that underlie the Bangalore study region have local granitic intrusions. As reported by Sekhar et al. [35], the depth of the groundwater table is merely a few meters at a few sites in Central Bangalore; in other places, however, it can be as deep as 70 m. The geology and fracture network, seasonal monsoon recharge, current and historical abstraction, and (in the case of Bangalore) urban leakage all impact the groundwater levels. The key issues in the Bangalore Urban district are sewage contamination and industrial pollution; because of these, a high nitrate concentration can be witnessed in the subsurface areas. The over-exploitation of groundwater resources (due to the increased urbanization), and the excavations for metro train construction are the impacts that have caused the mentioned factors [36].

3. Materials and Methods

3.1. Collection of Water Samples

A 6 km × 6 km grid map of the Bangalore Urban district was prepared using ArcView GIS software (Version 3). A total of 56 water samples (Fig. 1) were taken from the surrounding borewells and other drinking water sources from nearby sampling locations. Where a groundwater source was not available, surface water was collected as a sample source. Before collecting the water samples, they were kept running for 2–5 minutes before collecting them in pre-cleaned polyethylene bottles. Ex-situ parameters like pH, TDS, EC, temp and dissolved oxygen were analyzed at the sampling sites, while other water-quality parameters like nitrates, total hardness, phosphates, sulfates, chloride, and uranium were analyzed in the laboratory. Using the Global Positioning System (GPS), the locations of each sample were noted.

3.2. Uranium Estimations in Water Samples

The uranium concentrations that were present in the water samples were examined using an LF-2a LED Fluorimeter (manufactured by Quantalase Enterprises Pvt. Ltd., Indore, India). The instrument consisted of light-emitting diodes (LED) along with photo multiplier tubes (PMTs). When a water sample was placed in a quartz cuvette, a pulsed UV light was emitted at a 400 nm wavelength (which was passed through a suitable filter). The green fluorescence that was released due to the excitation of the uranium species at the applicable wavelength was measured by the photo multiplier tubes (PMTs) in this method. The uranium concentrations in the fluid samples specified the estimations of the fluorescence. Stable uranyl phosphate, a fluorescence-enhancing reagent, was produced by adding a sodium pyrophosphate solution [21]. Ortho-phosphoric acid (OPA) helped in maintaining the pH level of the reagent at 7 [16]. To verify the accuracy of the results, the laser fluorimeter (LF) was calibrated using a standard uranium solution of a known concentration, and reagent blanks were run with samples of distilled water [37]. A uranium stock solution of 100 μg/mL was used to prepare the working standard samples in order to calibrate and test the instrument's performance. To reduce errors during the sample analysis, an analytical balance and automated pipette were utilized. A sample of water was blended with 0.5 mL of 5% sodium pyrophosphate in a dry spotless cuvette (maintained at pH = 7), and the results were measured. Since the water samples were collected from several places with different chemical compositions, the matrix effect had to be avoided throughout the analysis by employing the standard addition procedure [38].

3.3. Determination of Other Physico-Chemical Parameters

During the pre-monsoon and post-monsoon seasons, numerous physico-chemical parameters were scientifically investigated, along with the assessments of uranium in the water samples from the Bangalore Urban district according to

Table 1. The analysis of the water was carried out in line with standard methods. pH and TDS (total dissolved solids) were measured using pH and TDS probes. Nitrates (NO_3^-), phosphates (PO_4^{3-}) and sulfates (SO_4^{2-}) were measured using a portable nitrate photometer (HI 96786), a phosphate HR-checker (HI 717), and a portable Sulfate photometer (HI 94751) supplied by Hanna Instruments India Pvt. Ltd. The total hardness (TH) in the water was calculated using the EDTA titrimetric technique. Using an ion-selective electrode (ISE) (HI 5522) that was supplied by Hanna Instruments India Pvt. Ltd., fluoride (F^-) was detected. Chloride (Cl^-) was determined using the argentometric method, and uranium (U) was analyzed using the LF 2a LED fluorimeter model supplied by Quantalase Enterprises Pvt. Ltd.

Table 1. Analysis of various physico-chemical parameters of water

Sample no.	Parameter	WHO (2011)/ BIS/ AERB	Parameter values			Method followed
			value	POM	PRM	
1	pH	6.5–8.5	min	6.9	7.1	pH probe
			max	8.0	8.3	
			average	7.38	7.59	
2	total dissolved solids (TDS) [mg/L]	500 (BIS)	min	125	132	TDS probe
			max	1150	1040	
			average	337.39	609.36	
3	nitrate [mg/L]	50	min	1.5	1.3	nitrate photometer
			max	81	22	
			average	13.39	12.93	
4	total hardness [mg/L]	600 (BIS)	min	15	65	EDTA titrimetric method
			max	755	520	
			average	360.00	370.88	
5	phosphate [mg/L]	none	min	0.2	0.3	phosphate checker
			max	2.9	2.5	
			average	1.20	1.36	
6	sulfate [mg/L]	500	min	2	12	sulfate photometer
			max	156	120	
			average	59.45	90.71	
7	fluoride [mg/L]	1.5 (BIS)	min	0.25	0.72	ion selective electrode
			max	1.98	1.90	
			average	1.05	1.40	
8	chloride [mg/L]	250 (BIS)	min	5	0	argentometric method
			max	285.91	84.00	
			average	55.75	44.00	
9	uranium [μg/L]	60 (AERB)	min	1.38	0.94	LED fluorimeter LF 2a
			max	96.52	98.79	
			average	24.57	23.52	

3.4. Correlation Analysis of Uranium with Water-Quality Parameters

After analyzing the uranium along with the other water-quality parameters, its significance with the different water-quality parameters was studied further [34]. The association between uranium and other water-quality parameters was assessed using the Number Cruncher Statistical System (NCSS). To determine the correlation coefficients, the coefficients of many sets of parameters were computed and used to build a correlation matrix [39]. The findings of the uranium tests were connected with the various indicators of water quality.

3.5. Human Risk-Assessment Due to Uranium Ingestion

The uranium concentrations were higher than the permitted limit at a few sample sites. Assessing the health impact on the general public becomes vital when people are exposed to higher uranium concentrations in their drinking water sources. When uranium is exposed to the environment, it affects human health; this can be classified as a radiation risk that is caused by the radiation of the isotopes of any uranium that is present in water and the chemical risk that is caused by its toxicity (as it is a radioactive element). The radiological and chemical risks that were assessed for the collected water samples will be discussed further [40].

4. Results and Discussion

4.1. Estimation of Uranium with Different Water-Quality Parameters

In the current investigation, 56 water samples were collected during the pre-monsoon and post-monsoon seasons. The uranium concentrations in the pre-monsoon season varied from 0.94 to 98.79 μg/L, and in the post-monsoon season, these varied from 1.38 to 96.52 μg/L. A few samples from both the pre-monsoon and post-monsoon seasons exceeded the AERB limit; Kadubeesanahalli (Sample No. 11) and Kaggalipura (Sample No. 32) witnessed higher uranium concentrations (76.85 and 98.79 μg/L, respectively) during the pre-monsoon season, whereas Dibburu (Sample No. 14) and Channenahalli (Sample No. 42) witnessed 96.57 and 84.99 μg/L, respectively, during the post-monsoon season (Fig. 3, Table 2).

The uranium concentrations that were discovered in the groundwater in this study were comparable to those that were discovered in previous recent investigations [6, 36]. The minimum uranium concentrations in the Bangalore Urban district were 0.94 (PRM) and 1.38 μg/L (POM), whereas the maximum concentrations were 98.79 (PRM) and 96.52 μg/L (POM) (Table 1). It could also be observed from the study that the uranium concentrations varied within shorter distances from the populations; this was in line with the similar tendencies that were mentioned by Nagaiah et al. [41]. This made it so that the distributions of the naturally occurring uranium in the groundwaters reflected the local environments [42].

As reported by Lapworth et al. [34] urban leakage in Bangalore led to a low-pH and low-bicarbonate groundwater hydrochemistry, thus reducing uranium's mobility and altering uranium's speciation. The local geology and physico-chemical environment may be responsible for the differences in the uranium concentrations at various distances. Leaching is more effective when bicarbonate is formed while water is seeping through the soil. This may be one of the mechanisms that underlay the high levels of uranium in the local groundwaters at a few sampling sites, but other explanations remain conceivable. Kadubeesanahalli is an IT hub, and Brigade Meadows (in Kaggalipura) is a group of high-rise apartments. The reason behind the slighter higher concentrations could have resulted from the overlying of the soils (one above the other). The leakage of septic tanks, the infiltration of wastewater, and (primarily) the decline of the groundwater table might have triggered geogenic contaminants with uranium mobilization to the groundwater from its sediments. The flow of the groundwater along with any geogenic contaminants through aquifer zones might have reached the bore wells, which might have been a contributing factor to the rises in the uranium concentrations [43].

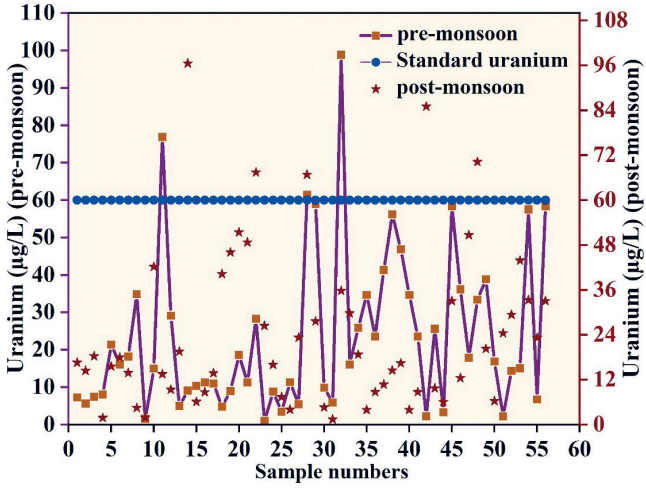

Fig. 3. Variations of uranium contents during pre-monsoon and post-monsoon seasons in Bangalore Urban district

The majority of the groundwater samples in the study areas were of the alkaline type; pH levels varied from 6.9 to 8 during the post-monsoon season and from 7.1 to 8.3 during the pre-monsoon season (Fig. 4) [44]. Meanwhile, the total dissolved solids varied from 125 to 1150 mg/L during the post-monsoon season and from 132 to 1040 mg/L during the pre-monsoon season (Fig. 5). The samples that were collected during the post-monsoon season noted a high TDS value of 1150 mg/L; during the pre-monsoon season, they were up to 1040 mg/L. Because too many minerals

were dissolved, the TDS of certain water samples exceeded the prescribed limit. One explanation for these increases in the TDS contents could have been due to increases in urban runoff and the use of agricultural fertilizers [45, 46]. The phosphate concentrations ranged from 0.2 to 2.9 mg/L in the post-monsoon and from 0.3 to 2.5 mg/L in the pre-monsoon seasons (Fig. 6) [41–44]. The sulfate concentrations varied from 12 to 120 mg/L during the pre-monsoon and from 2 to 120 mg/L during the post-monsoon seasons (Fig. 7). The sulfate concentrations were well within 200 mg/L (as per the BIS standards). The nitrate concentrations varied from 1.3 to 22 mg/L during the pre-monsoon and from 1.5 to 81 mg/L during the post-monsoon seasons (Fig. 8). Overall, our data sets showed no discernible correlation between the uranium and nitrates, which ruled out the possibility that fertilizers were the primary sources of the uranium. The nitrate levels were well within BIS recommendations.

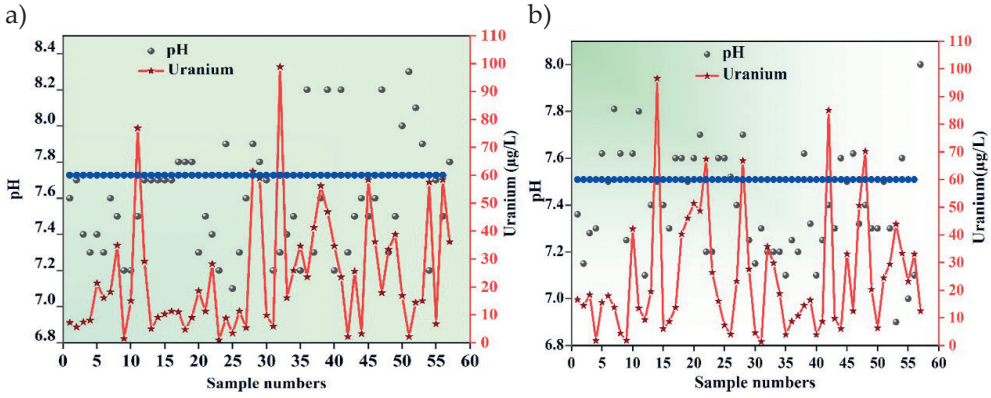

Fig. 4. Variations of uranium with pH during pre-monsoon (a) and post-monsoon (b) seasons in Bangalore Urban district

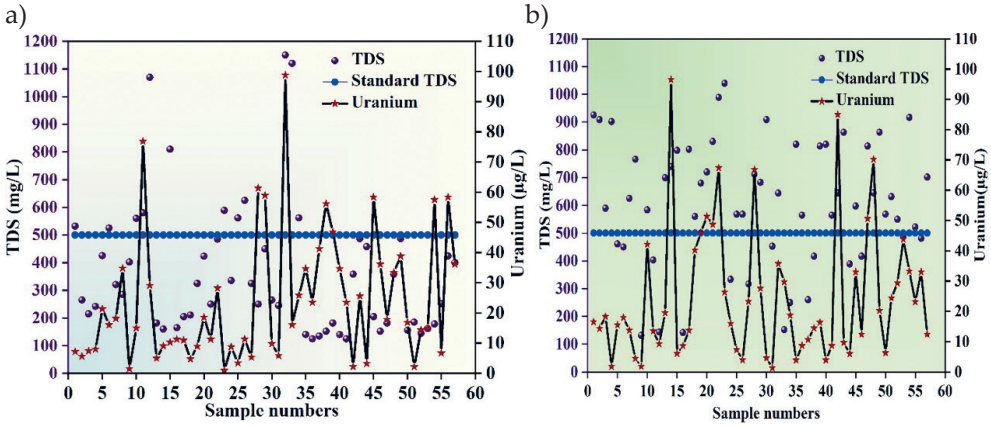

Fig. 5. Variations of TDS along with uranium during pre-monsoon (a) and post-monsoon (b) seasons in Bangalore Urban district

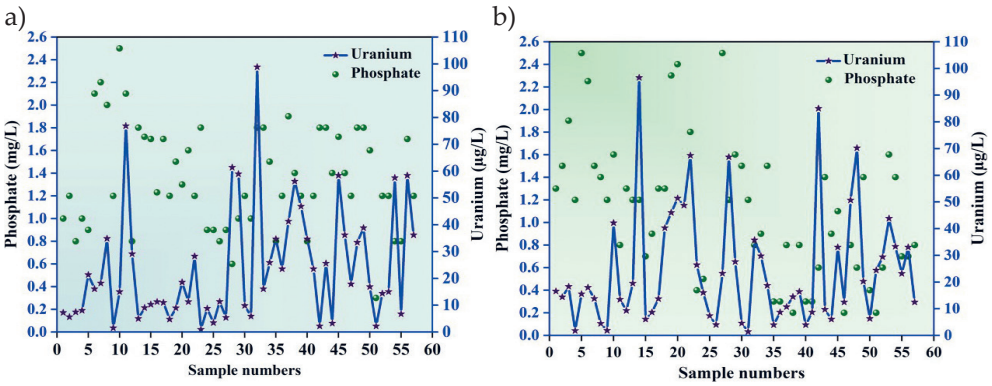

Fig. 6. Variations of phosphate with uranium during pre-monsoon (a) and post-monsoon (b) seasons in Bangalore Urban district

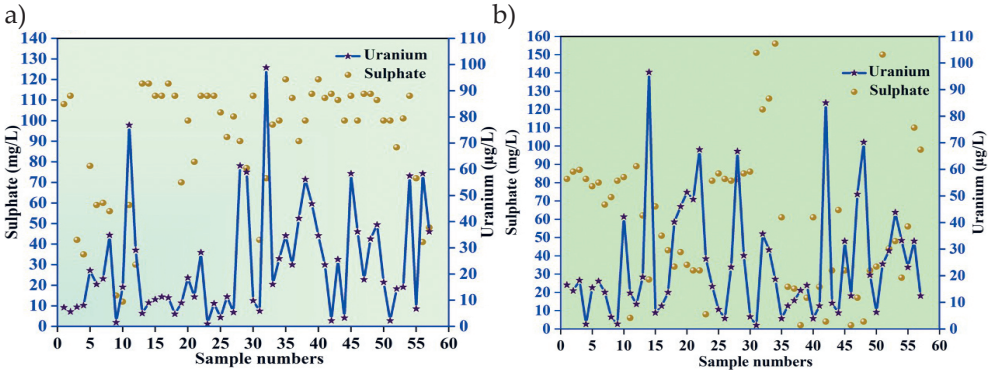

Fig. 7. Uranium variations with sulfate during pre-monsoon (a) and post-monsoon (b) seasons in Bangalore Urban district

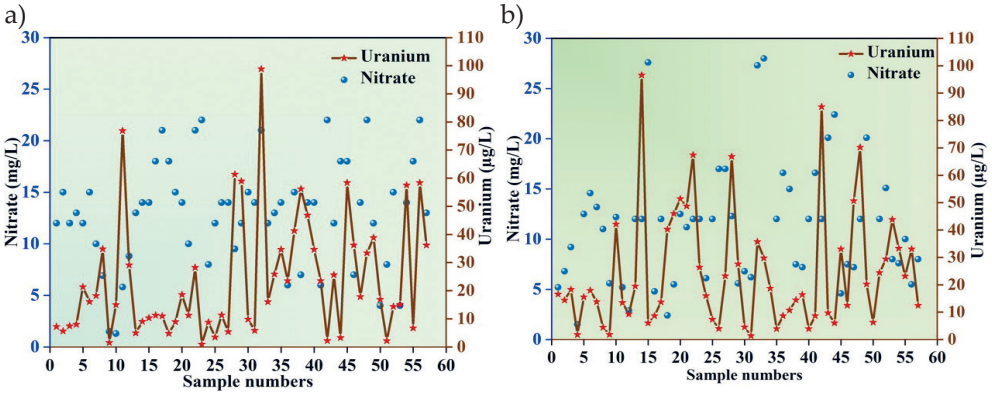

Fig. 8. Variations of uranium with nitrates during pre-monsoon (a) and post-monsoon (b) seasons in Bangalore Urban district

The calcium hardness (CaH) varied from 30 to 460 mg/L during the pre-monsoon and from 5 to 495 mg/L during the post-monsoon seasons (Fig. 9). The magnesium hardness (MgH) varied from 0 to 320 mg/L during the pre-monsoon and from 0 to 625 mg/L during the post-monsoon seasons (Fig. 10).

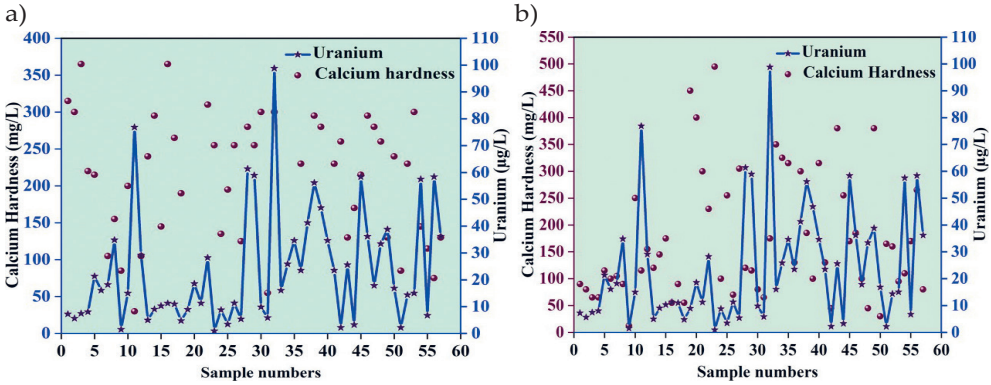

Fig. 9. Variations of calcium hardness with uranium during pre-monsoon (a) and post-monsoon (b) seasons in Bangalore Urban district

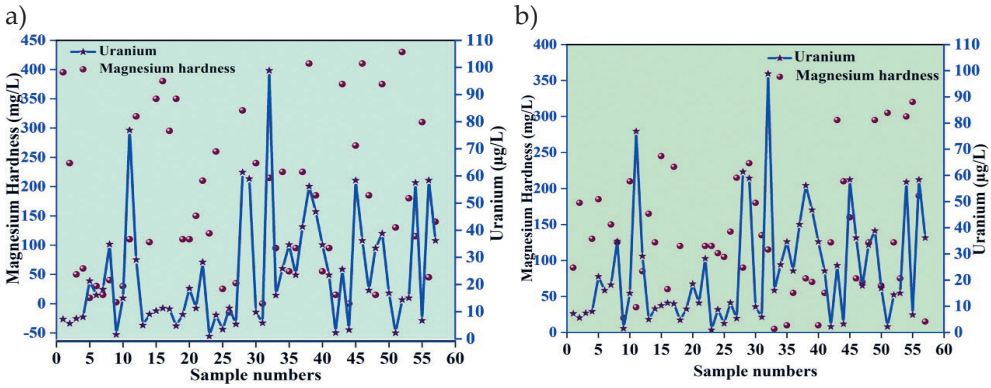

Fig. 10. Variations of magnesium hardness with uranium during pre-monsoon (a) and post-monsoon (b) seasons in Bangalore Urban district

The fluoride concentrations varied from 0.25 to 1.98 mg/L during the post-monsoon and from 0.72 to 1.9 mg/L during the pre-monsoon seasons (Fig. 11). They were within the prescribed limit; these might exceed the limit if no proper monitoring is followed; the risk of dental fluorosis increases with fluoride concentration, while the risk of skeletal fluorosis increases at higher concentrations. The high fluoride contents in the groundwater may have been caused by increases in infiltration via weathered rocks, the use of phosphatic fertilizers, and other industrial activities [47]. Hence, the sources of groundwater supplies to villages with high concentrations of fluoride must be treated with defluoridation techniques.

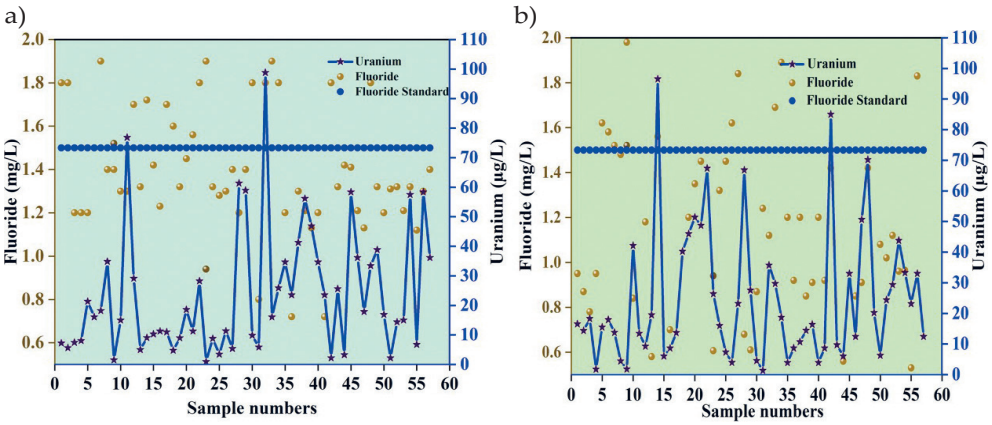

Fig. 11. Variations of uranium with fluoride during pre-monsoon (a) and post-monsoon (b) seasons in Bangalore Urban district

As shown in Figure 12, the chloride concentrations varied from 0 to 84 mg/L during the pre-monsoon and from 5.00 to 285.91 mg/L during the post-monsoon seasons.

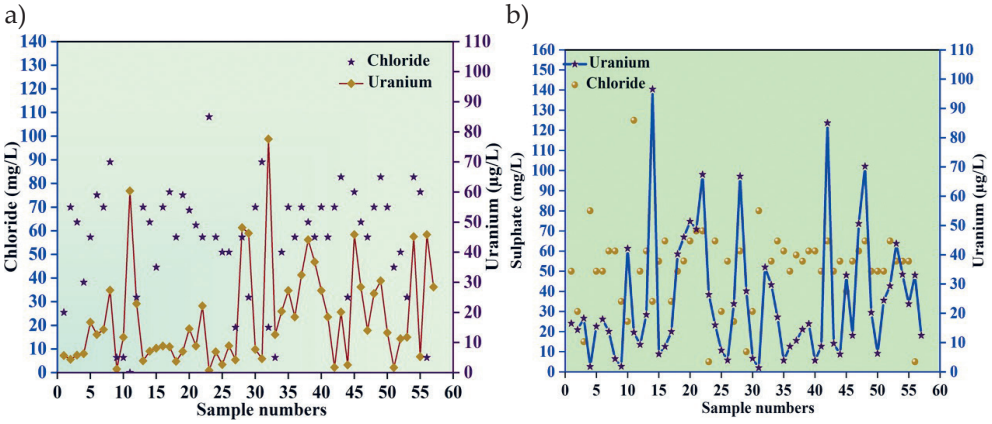

Fig. 12. Variations of uranium with chloride during pre-monsoon (a) and post-monsoon (b) seasons in Bangalore Urban district

Figure 13 illustrates the schematic ion ratios of Ca^{2+}/Mg^{2+} that are used to trace the sources of calcium and magnesium in groundwater. According to recently conducted research that was carried out by Srinivasamoorthy et al. [48], it indicated that, if the ratio of $Ca^{2+}/Mg^{2+} > 2$, this infers that silicate minerals have an impact by adding calcium and magnesium ions to the groundwater. Along similar lines,

Ajay Kumar et al. [4] inferred that, if the molar ratio of $Ca^{2+}/Mg^{2+} > 1$, there might have been either a high decomposition of calcium-bearing minerals like calcite, anhydrite, and gypsum or a dissolution of calcium-containing silicate minerals (igneous – including granite rocks) during the geochemical processes. As compared to our study, around 50% of the samples had levels that were greater than 2 in both the pre-monsoon and post-monsoon seasons. The Closepet granites and gneiss rock structures contained silica, which might have been the reason for the increase in the ratio of $Ca^{2+}/Mg^{2+} > 2$. In the post-monsoon season, fewer than 25% of the samples fell below the 1-ratio line, which means that the Ca^{2+} might have precipitated as $CaCO_3$ due to the ion-exchange process. As the magnesium composition is comparatively less in the parent rock of the Bangalore Urban district, it has been less-witnessed.

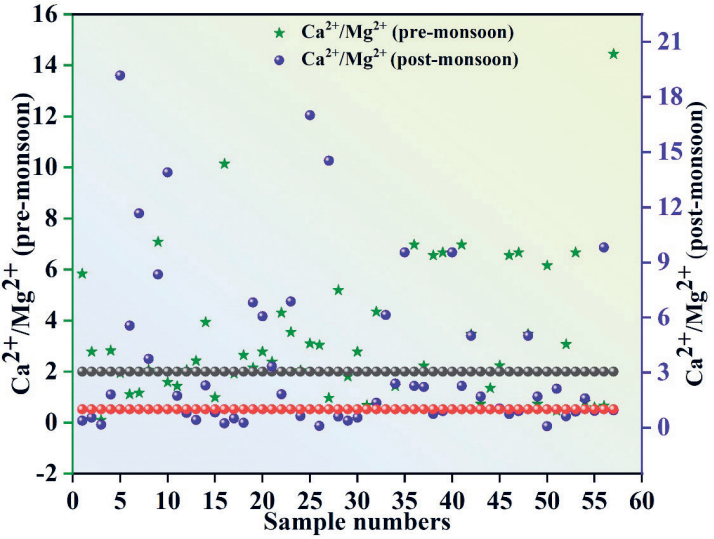

Fig. 13. Relationship of major ions: scatter diagram of Ca^{2+}/Mg^{2+} during pre-monsoon and post-monsoon seasons

However, recent studies that were conducted by Lapworth et al. [34] indicated that, urban leakage in Bangalore caused low pH and low bicarbonate groundwater hydrochemistry, which changed uranium speciation and decreased uranium mobility. Nevertheless, identical uranium concentrations in comparable environments have been recorded in India – both in the crystalline basement and the alluvial soil aquifer systems. As a result, the study highlighted the uranium concentrations in various villages inside the Bangalore Urban zone [48].

Table 2 illustrates details of the sampling locations and the values of the different water-quality parameters: pH, total dissolved solids (TDS), total hardness, nitrates, phosphates, sulfates, chloride, fluoride, and uranium concentrations.

Table 2. Details of sampling location along with values of different water quality parameters

Sample no.	Location details	pH		TDS [mg/L]		Nitrates [mg/L]		Total hardness [mg/L]		Phosphates [mg/L]		Sulfates [mg/L]		Chloride [mg/L]		Fluoride [mg/L]		Uranium [μg/L]	
		PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM
1	Kammanahalli	7.6	7.3	926	532	12	5.2	405	485	1	1.3	108	82	20	50	0.83	0.56	7.23	16.5
2	RR Nagar	7.7	7.15	909	265	15	6.8	480	320	1.2	1.5	112	86	55	30	1.39	2.71	5.62	14.3
3	Ashok Nagar	7.4	7.28	590	215	12	9.2	300	115	0.8	1.9	42	87	50	15	3.82	0.90	7.42	18.3
4	Kalyan Nagar	7.3	7.3	902	242	13	1.5	350	125	1	1.2	35	82	30	80	3.07	0.25	8.01	1.76
5	Jal Vayu Vihar	7.4	7.62	461	425	12	12.5	400	125	0.9	2.5	78	78	45	50	2.12	0.17	21.3	15.5
6	BTM layout	7.3	7.5	450	525	15	14.5	500	130	2.1	2.25	59	80	59.	50	2.3	0.25	16.0	17.9
7	Whitefield	7.6	7.81	625	321	10	13.2	255	120	2.2	1.5	60	68	55	60	1.85	0.13	18.2	13.7
8	Mahadevpura	7.5	7.62	766	285	6.9	11	280	130	2	1.4	56	72	70	60	2	0.98	34.8	4.44
9	K R Puram	7.2	7.25	132	402	1.5	5.6	105	15	1.2	1.2	15	81	5	35	8.89	0.39	1.52	1.85
10	Kumari Lotus Apartments	7.2	7.62	584	560	1.3	12.2	410	280	2.5	1.6	12	83	5	25	7.3	0.28	14.9	42.1
11	Kadubeesanahalli	7.5	7.8	403	580	5.8	5.2	65	225	2.1	0.8	59	6	–	125	4.52	0.81	76.8	13.4
12	Kengeri	7.7	7.1	144	1070	8.8	2.9	190	475	0.8	1.3	30	89	25	50	3.54	0.91	29.1	9.3
13	Sonenahalli	7.7	7.4	700	182	13	12	405	600	1.8	1.2	118	62	55	60	2.84	0.24	4.98	19.5
14	Dibbur	7.7	7.5	740	160	14	12	420	250	1.72	1.2	118	27	50	35	2.36	3.2	9.06	96.5
15	Mathkur	7.7	7.4	798	810	14	27.6	390	525	1.7	0.7	112	67	35	55	2.36	0.24	10.2	6.07
16	Hesaragatta	7.7	7.3	142	165	18	4.8	425	435	1.23	0.9	112	51	55	65	1.79	4.25	11.2	8.64
17	Ganigarahalli	7.8	7.6	802	205	21	12	495	385	1.7	1.3	118	43	60	35	1.02	0.28	10.9	13.7
18	Gangondanahalli	7.8	7.6	560	211	18	2.4	310	405	1.2	1.3	112	34	45	50	1.82	2.68	4.75	40.2

Table 2. cont.

Sample no.	Location details	pH		TDS [mg/L]		Nitrates [mg/L]		Total hardness [mg/L]		Phosphates [mg/L]		Sulfates [mg/L]		Chloride [mg/L]		Fluoride [mg/L]		Uranium [μg/L]	
		PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM
19	Vidyaranyapura	7.8	7.5	680	325	15	5.5	412	560	1.5	2.3	70	42	59	55	1.52	1.76	8.95	45.9
20	Jalahalli	7.3	7.6	720	423	14	12.5	520	510	1.3	2.4	100	35	54	65	1.78	1.66	18.5	51.3
21	Abbigere	7.5	7.7	830	250	10	11.2	510	450	1.6	2.8	80	32	49	70	3.34	0.57	11.2	48.6
22	Byadarahalli	7.4	7.2	989	485	21	12	430	440	1.2	1.8	112	32	45	70	4.45	0.52	28.2	67.4
23	Kuntanahalli	7.2	7.2	1040	589	22	12	375	615	1.8	0.4	112	8	85	5	5.4	0.21	0.94	26.3
24	Chikkagubbi	7.9	7.6	333	336	8	6.1	245	360	0.9	0.5	112	81	45	65	4.7	0.56	8.77	15.97
25	Aduru	7.1	7.6	568	562	12	12	300	280	0.9	2.9	104	85	40	30	4.2	1.58	3.45	7.35
26	Maralakunte	7.3	7.52	568	625	14	17	395	55	0.8	2.8	92	82	40	55	3.69	2.44	11.3	3.97
27	Budigere	7.6	7.4	317	325	14	17	340	340	0.9	2.5	102	81	15	25	1.42	2.22	5.37	23.2
28	Ullal	7.9	7.7	712	250	9.5	12.3	370	450	0.6	1.2	90	82	45	60	0.72	0.98	61.3	66.7
29	Padmana-bhanagar	7.8	7.25	683	450	12	5.6	490	610	1	1.6	77	85	25	10	0.82	0.83	58.9	27.5
30	R R Nagar	7.7	7.15	909	265	15	6.8	480	320	1.2	1.5	112	86	55	30	0.29	1.52	9.84	4.57
31	BHEL Layout	7.2	7.3	453	245	14	6.2	190	115	1	1.2	42	151	70	80	0.80	0.92	5.84	1.38
32	Kaggalipura	7.3	7.2	644	1150	21	27.3	415	390	1.8	0.8	72	120	15	285	1.4	0.89	98.7	35.7
33	Talaghattapura	7.4	7.2	152	1120	12	28	465	445	1.8	0.9	98	126	5	55	1.2	1.51	16.0	29.7
34	Anekal	7.5	7.2	250	562	13	56	432	555	1.5	1.5	100	156	40	65	1.62	0.54	25.8	18.6
35	Gottigere	7.2	7.1	820	140	14	12	455	370	0.8	0.3	120	61	55	60	1.3	1.62	34.6	3.92
36	Banerghatta Road	8.2	7.25	565	125	6	16.6	285	225	1.2	0.3	111	23	45	50	1.4	1.04	23.5	8.68

Table 2. cont.

37	Singasandra	7.3	7.2	260	135	15	15	350	425	1.9	0.8	90	22	55	58	1.8	0.96	41.2	10.6
38	Harapanahalli	7.6	7.62	417	152	7	7.5	370	595	1.4	0.2	100	2	49	55	1.4	0.81	56.1	14.4
39	Chandapura	8.2	7.32	814	182	14	7.2	350	285	1.2	0.8	113	17	45	60	1.2	0.81	46.8	16.3
40	Chandrashek-harapura	7.2	7.1	820	140	14	12	455	370	0.8	0.3	120	61	55	60	1.3	0.62	34.6	3.92
41	Golahalli	8.2	7.25	565	125	6	16.6	285	225	1.2	0.3	111	23	45	50	1.3	0.65	23.5	8.68
42	Chennenahalli	7.3	7.4	645	358	22	12	385	60	1.8	0.6	113	4	55	65	1.2	0.86	2.2	84.9
43	Dodda Alada Mara	7.5	7.3	863	487	12	20.1	425	755	1.8	1.4	110	32	65	50	1.3	0.58	25.5	9.71
44	Kitthanahalli	7.6	7.6	389	458	18	22.4	380	255	1.4	0.9	100	65	25	55	1.32	0.61	3.25	6.02
45	Gejjigadahalli	7.5	7.5	597	205	18	4.6	375	440	1.72	1.1	112	32	60	40	1.3	0.59	58.3	33.0
46	Attibele	7.6	7.62	417	152	7	7.5	370	595	1.4	0.2	100	2	50	55	1.49	0.84	36.1	12.4
47	Sarjapura	8.2	7.32	814	182	14	7.2	350	285	1.2	0.8	113	17	45	60	1.2	0.68	17.8	50.6
48	Chikka Thirupati Rd	7.3	7.4	645	358	22	12	385	60	1.8	0.6	113	4	55	65	1.25	0.52	33.4127	70.1
49	Bukkasagara	7.5	7.3	863	487	12	20.1	425.00	755	1.8	1.4	110	32	65	50	1.6	0.96	38.8	20.2
50	Vaddarapalya	8	7.3	568	156	4	81	305	655	1.6	0.4	100	34	55	50	1.7	1.06	16.8	6.28
51	Vinayaka Nagar, Anekal	8.3	7.5	631	185	8	12	390	295	0.3	0.2	110	150	35	50	1.2	1.02	2.17	24.4
52	Yelahanka	8.1	7.3	550	145	15	15.1	355	590	1.2	0.6	100	44	40	65	1.48	1.04	14.3	29.3
53	Husmaranahalli	7.9	6.9	488	162	4	8	375	275	1.2	1.6	100	48	25	55	1.2	1.53	15.0	43.8
54	Kanakapura	7.2	7.6	917	178	14	7.6	445	225	0.8	1.4	87	28	65	55	1.2	1.32	57.5	33.2
55	Gerahalli	7.7	7	522	252	18	10	435	480	0.8	0.7	101	56	60	55	1.82	1.39	6.71	23.1
56	Haniyur	7.5	7.1	481	424	22	5.5	265	310	1.7	0.7	112	110	5	5	1.2	1.85	58.3	33.0

4.2. Analysis of Uranium with Different Water-Quality Parameters

Utilizing the Statistical Package of Number Cruncher Statistical System (NCSS) program, it was possible to determine whether the water-quality parameters (n = 9) and uranium concentrations were correlated. A Pearson's correlation matrix approach was used, as the data was normally distributed.

Table 3 lists the correlation matrix that the software extracted during the pre-monsoon season. During this season, uranium showed weakly correlated positive levels with TDS (0.06), nitrates (0.05), and phosphates (0.16). Due to the extensive abstraction of the groundwater for household and industrial purposes, it exhibited considerable seasonal variability [35]. As reported, the Bangalore samples' hydrochemistry demonstrated low pH levels, low bicarbonate, decreased U mobility, lower occurrence, unique U speciation, and mineral saturation. Therefore, no such direct correlation could be observed in either the pre-monsoon or post-monsoon seasons (Table 4). The total hardness witnessed a positive correlation with TDS, fluoride, chloride and sulfates; this showed that the primary source of the cations was the weathering of the bedrock. Phosphates witnessed weakly correlated positive levels with fluoride, chloride, and nitrates. As mentioned in [34] samples that were drawn from Bangalore city also witnessed low phosphorous contents. Sulfates were found to have weak positive correlations with the pH levels, total dissolved solids, fluoride, chloride, and nitrates. Nitrates witnessed weakly positive correlations with TDS, fluoride, and chloride. Chloride had a positive correlation with total dissolved solids, while fluoride had a weak correlation with total dissolved solids. Apart from the above-mentioned positive correlations, the rest were negatively correlated. Referring to the table that was computed by Keith S. Taber, the alpha values were characterized as follows: excellent (0.93–0.94), strong (0.91–0.93), dependable (0.84–0.90), robust (0.81), reasonably high (0.76–0.95), high (0.73–0.95), good (0.71–0.91), relatively high (0.70–0.77), slightly low (0.68), reasonable (0.67–0.87), adequate (0.64–0.85), moderate (0.61–0.65), satisfactory (0.58–0.97), acceptable (0.45–0.98), sufficient (0.45–0.96), not satisfactory (0.4–0.55), and low (0.11). The Cronbach's alpha score of Pearson's matrix that was obtained during the pre-monsoon season was 0.3781, which was said to be low [49, 50].

Table 4 lists the correlation information during the post-monsoon season that the software extracted. During the pre-monsoon season, uranium showed a weak positive correlation with the pH levels (0.066), chloride (0.038), nitrates (0.062), and phosphates (0.08). The total hardness had weak positive correlations with the pH levels, chloride, nitrates, and phosphates. Phosphates witnessed weak positive correlations with the pH levels, TDS, fluoride, and sulfates. As mentioned in [34], samples that were drawn from Bangalore city also witnessed low phosphorous contents. Sulfates found weak positive correlations with TDS, fluoride, chloride, and nitrates. Chloride had weak positive correlations with the pH levels, total dissolved solids, and fluoride. Fluoride showed weak positive correlations with the total dissolved

solids and pH levels. As the water-quality parameters had weak positive correlations, it can be inferred from the results that each parameter functioned on its own and was independent of the others. Apart from the aforementioned weak positive correlations, the rest were negatively correlated. The Cronbach's alpha score of Pearson's matrix that was obtained during the pre-monsoon season was 0.1939, which was said to be less reliable.

Table 3. Uranium correlation matrix for various pre-monsoon water-quality parameters

	pH	TDS	F^-	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	TH	U
pH	1.00								
TDS	−0.05	1.00							
F^-	−0.29	0.15	1.00						
Cl^-	−0.06	0.41	−0.07	1.00					
NO_3^-	−0.29	0.25	0.41	0.28	1.00				
SO_4^{2-}	0.22	0.34	0.09	0.42	0.26	1.00			
PO_4^{3-}	−0.26	−0.01	0.34	0.02	0.05	−0.10	1.00		
TH	−0.11	0.41	0.26	0.36	0.35	0.48	−0.01	1.00	
U	−0.12	0.07	−0.06	−0.13	0.00	−0.04	0.17	−0.07	1.00

Cronbach's alpha – 0.3781.
TDS, F^-, Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, and TH were measured in mg/L; U in μg/L.

Table 4. Uranium correlation matrix for various post-monsoon water-quality parameters

	pH	TDS	F^-	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{3-}	TH	U
pH	1.00								
TDS	−0.02	1.00							
F^-	0.22	0.14	1.00						
Cl^-	0.05	0.35	0.05	1.00					
NO_3^-	−0.11	0.11	0.09	0.10	1.00				
SO_4^{2-}	−0.08	0.36	0.36	0.09	0.07	1.00			
PO_4^{3-}	0.21	0.24	0.17	−0.12	−0.13	0.15	1.00		
TH	0.07	−0.06	−0.03	0.04	0.06	−0.30	0.08	1.00	
U	0.07	−0.06	−0.03	0.04	0.06	−0.30	0.08	1.00	1.00

Cronbach's alpha – 0.1939.
TDS, F^-, Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, and TH were measured in mg/L; U in μg/L.

4.3. Risk-Assessment of Human Health

Since India's groundwater supplies the majority of its drinking and agricultural water, the occurrence of high groundwater U concentrations could pose a risk to the general public's health. In line with the values that were obtained on uranium concentrations, it was inferred that its concentration exceeded the prescribed limit in a few samples. The current study was extended to evaluate excess cancer risk based on the estimated uranium values. The radiological and chemical risks will now be addressed in detail [40].

Radiological Risk-Assessment

The purpose of a radiological risk-assessment is to identify the radiation threats that may arise from the presence of different types of ionizing radiation by the various chemical substances that are present in water. These hazards are rarely assessed in drinking water, as this has less of a public health significance. The excess cancer risk (also called radiological risk) that can be attributed to uranium concentration is mentioned in Equations (1) and (2):

$$RR = U \cdot RF \tag{1}$$

where: RR – radiological risk, U – uranium [Bq/L], RF – risk factor.

The factors in Equation (1) are as follows:

$$U = UC \cdot CF \tag{2}$$

where: UC – uranium concentration [μg/L], CF – conversion factor (0.025 Bq/μg);

$$RF = RC \cdot WIR \cdot D \tag{3}$$

where: RC – risk coefficient (cancer mortality risk/cancer morbidity risk), WIR – water ingestion rate [L/day], D – duration of total exposure [days].

Here, RF is the risk factor that is mentioned in Equation (3), the water ingestion rate is considered to be 4.05 L/day, and the average Indian life expectancy is considered to be 70.2 years (Press Information Bureau Government of India). Mortality represents the incidence of fatal cancer, and morbidity highlights the incidences of all cancers (fatal and non-fatal). Despite being a radioactive element without a stable isotope, U-238 is the most common naturally occurring form of uranium (>99.2%), and it is also the least radioactively dangerous. The cancer mortality and morbidity risks are featured in Tables 5 and 6 during the pre-monsoon and post-monsoon seasons. The cancer mortality and morbidity risks were calculated by considering the cancer mortality coefficient to be $1.19 \cdot 10^{-9}$/Bq and the cancer morbidity coefficient to be $1.84 \cdot 10^{-9}$/Bq [20, 40, 51]. For the Bangalore Urban district, the cancer mortality risk ranged from $3.96 \cdot 10^{-8}$ to $4.166 \cdot 10^{-6}$ during the pre-monsoon season (with an average of $9.918 \cdot 10^{-7}$) and $5.81 \cdot 10^{-8}$ to $4.07 \cdot 10^{-6}$ during the post-monsoon period (with an average of $1.07 \cdot 10^{-6}$). Bangalore's cancer morbidity

risk varied from $6.129 \cdot 10^{-8}$ to $6.44 \cdot 10^{-6}$ during the pre-monsoon season (with an average of $1.53 \cdot 10^{-6}$) and $8.9 \cdot 10^{-6}$ to $6.2 \cdot 10^{-6}$ during the post-monsoon period (with an average of $1.6 \cdot 10^{-6}$). From the obtained results, it can be observed that all of the values of the cancer mortality and morbidity risks were well within the acceptable limit of 10^{-4}. Consuming the water samples is, therefore, radiologically safe [20].

Table 5. Concentration of uranium with cancer mortality risk, cancer morbidity risk, and LADD, along with statistical parameters of Bangalore Urban district during pre-monsoon period

Statistical parameters	Uranium [μg/L]	Cancer mortality risk	Cancer morbidity risk	LADD [μg/kg/day]	HQ
Minimum	0.94	$3.96 \cdot 10^{-8}$	$6.12 \cdot 10^{-8}$	0.06	0.11
Average	23.52	$9.91 \cdot 10^{-7}$	$1.53 \cdot 10^{-6}$	1.72	2.87
Maximum	98.79	$4.16 \cdot 10^{-6}$	$6.44 \cdot 10^{-6}$	7.23	12.06
Median	16.47	$6.94 \cdot 10^{-7}$	$1.07 \cdot 10^{-6}$	1.20	2.01
SD	20.66	$8.71 \cdot 10^{-7}$	$1.34 \cdot 10^{-6}$	1.51	2.52
Q_{25}	8.20	$3.45 \cdot 10^{-7}$	$5.34 \cdot 10^{-7}$	0.60	1.00
Q_{75}	34.654	$1.46 \cdot 10^{-6}$	$2.25 \cdot 10^{-6}$	2.54	4.23
P_{10}	4.10	$1.72 \cdot 10^{-7}$	$2.67 \cdot 10^{-7}$	0.30	0.50
P_{90}	57.51	$2.42 \cdot 10^{-6}$	$3.74 \cdot 10^{-6}$	4.21	7.02

Explanations: SD – standard deviation; Q_{25} – 1st quartile; Q_{75} – 3rd quartile; P_{10} – 10th percentile; P_{90} – 90th percentile; LADD – lifetime average daily dose; HQ – hazard quotient.

Table 6. Concentration of uranium with cancer mortality risk, cancer morbidity risk, and LADD, along with statistical parameters of Bangalore Urban district during post-monsoon period

Statistical parameters	Uranium [μg/L]	Cancer mortality risk	Cancer morbidity risk	LADD [μg/kg/day]	HQ
Minimum	1.38	$5.81 \cdot 10^{-8}$	$8.99 \cdot 10^{-8}$	0.10	0.16
Average	25.60	$1.07 \cdot 10^{-6}$	$1.66 \cdot 10^{-6}$	1.87	3.12
Maximum	96.52	$4.07 \cdot 10^{-6}$	$6.29 \cdot 10^{-6}$	7.07	11.78
Median	19.09	$8.05 \cdot 10^{-7}$	$1.24 \cdot 10^{-6}$	1.39	2.33
SD	21.30	$8.98 \cdot 10^{-7}$	$1.38 \cdot 10^{-6}$	1.56	2.60
Q_{25}	9.402	$3.96 \cdot 10^{-7}$	$6.13 \cdot 10^{-7}$	0.68	1.14
Q_{75}	33.29	$1.40 \cdot 10^{-6}$	$2.17 \cdot 10^{-6}$	2.43	4.06
P_{10}	4.505	$1.89 \cdot 10^{-7}$	$2.93 \cdot 10^{-7}$	0.33	0.55
P_{90}	50.99	$2.15 \cdot 10^{-6}$	$3.32 \cdot 10^{-6}$	3.73	6.22

Explanations: SD – standard deviation; Q_{25} – 1st quartile; Q_{75} – 3rd quartile; P_{10} – 10th percentile; P_{90} – 90th percentile; LADD – lifetime average daily dose; HQ – hazard quotient.

Chemical Risk

The chemical risk that is caused due to the ingestion of uranium-contaminated water is assessed based on the values of the hazard quotient (HQ) as a non-carcinogenic impact. The chemical hazard that is caused due to uranium ingestion targets the kidneys and lungs [31]. Radiologic toxic effects typically occur at higher exposure levels than chemical toxic effects (which primarily affect the kidneys). The average daily dose of uranium that is consumed throughout one's lifespan was taken into consideration while calculating the chemical toxicity risk, keeping the reference dose (RFD) as 1 μg/kg/day as the standard criterion. The hazard quotient and lifetime average daily dose (LADD) can be calculated as shown in Equations (4) and (5) [52]:

$$HQ = \frac{LADD}{RFD} \tag{4}$$

$$LADD = \frac{EPC \cdot IR \cdot EF \cdot LE}{AT \cdot BW} \tag{5}$$

where EPC is the exposure point of concentration [μg/L], IR is the water ingestion rate (taken as 4.05 L/day), EF is the exposure frequency (taken as 350 days), LE is life expectancy (taken as 70.2 years; i.e., 25,703.2 days), AT is the average time [days], and BW is body weight (53 kg). Here, the reference dose can also be referred to as the tolerable daily dose (TDI). Kurttio et al. [30] researched epidemiological studies on consuming water with significant amounts of uranium in it, wherein the WHO (World Health Organization) has prescribed a new guideline value of 1 μg/kg/day as the TDI value. A statistical analysis was performed that analyzed the minimum value, maximum value, average, median (the number in the center of the list of values that are in ascending order), standard deviation (this represents a "typical" variance from the average), Q_{25} and Q_{75} (these quantiles are the cut points that divide a probability distribution's range into continuous intervals with equal probabilities; more precisely, they divide a sample's observations into equal groups), P_{10} (P_{10} is the value that is greater than 10% of the data points), and P_{90} (P_{90} is the value that is greater than 90% of the data points). During the pre-monsoon season, the LADD values ranged from 0.101 to 7.072 μg/kg/day (with an average of 1.876 μg/kg/day) as per Table 5, and the HQ (hazard quotient) values varied from 0.16 to 11.78 (with an average value of 3.127). During the post-monsoon season, the LADD values ranged from 0.069 to 7.239 μg/kg/day (with an average of 1.72 μg/kg/day) as per Table 6, and the HQ values varied from 0.115 to 12.065 (with an average value of 2.872) [28]. When the HQ values were compared accordingly (keeping the RFD value as 1), an apartment at Kaggalipura (Brigade Meadows) witnessed an HQ value of 12.065 during the pre-monsoon season; similarly, Dibbur Village reported an HQ value

of 11.78 during the post-monsoon season. These were 11- to 12-times greater than the HQ value of 1 (Fig. 14). These findings demonstrated that the residents of this area were vulnerable to chemical toxicity as a result of consuming uranium. This reference line is implacable to the HQ value of 2.872 that was obtained during the post-monsoon period. By considering the lower cases (P10) as 0.501 and 0.55 during the pre-monsoon and post-monsoon periods, the people were safe from chemical toxicity [23]. The drinking water had an HQ value that was below 1 and was suitable for human consumption; however, the people were 6–7 times more susceptible to chemical poisoning when the upper case (P90) was considered.

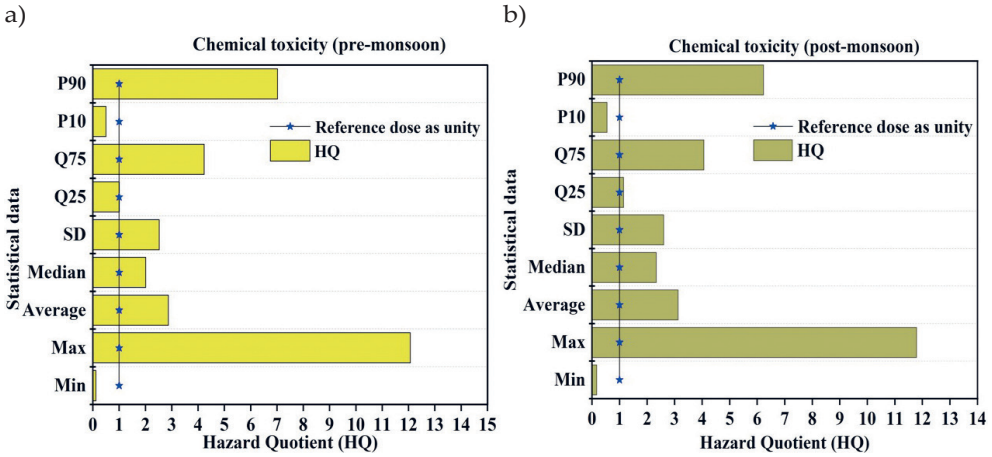

Fig. 14. Statistical data of chemical toxicity during pre-monsoon (a) and post-monsoon (b) seasons

5. Conclusion

The present study focused on the distribution of uranium in groundwater samples from the Bangalore Urban district as well as its radiological and chemical risk-assessment. According to a data analysis of the current investigation, more than 90% of the water samples were below the acceptable limit of 60 μg/L [53]. Very few samples exceeded the AERB limit from either the pre-monsoon or post-monsoon seasons.

The study highlighted the spatial and temporal distribution of uranium as well as its radiological and chemical risk impacts that are caused when its concentration exceeds 60 μg/L. This study revealed the chemical toxicity that is caused due to uranium consumption through its values of the hazard quotient (HQ). Hence, consuming water with uranium concentrations of greater than 60 μg/L is carcinogenic to human health. Stating its above significance, it is high time to adopt periodic water

analyses and other relevant clinical investigations in the Bangalore Urban district. Hence, the proper monitoring and treatment of high uranium drinking water sources in this area are necessary in order to protect public health, and more research is required to comprehend the hazards to public health that are caused by uranium in the groundwaters in granitic aquifers.

Author Contributions

Poojashri Ravindra Naik: conceptualization, methodology, formal analysis, investigation, data curation, writing – original draft preparation, writing – review and editing.

Vinod Alurdoddi Rajashekara: validation, visualization, review and editing, supervision.

Rajalakshmi Mudbidre: project management, formal analysis, data curation and supervision.

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