Assessment of the groundwater quality by using multivariate approach and non-carcinogenic risk of uranium in the inhabitants of District Bastar, Chhattisgarh Central India

Mayank Singh, Pokhraj Sahu, Kavita Tapadia, and Dalchand Jhariya

Department of Chemistry, National Institute of Technology, Raipur, CG
Bharat Oil and Waste Management Ltd, Roorkee, Uttarakhand
Department of Geology, National Institute of Technology, Raipur, CG
*Corresponding author. E-mail: ktapadia.chy@nitrr.ac.in

ABSTRACT

The elevated levels of uranium found in 17 state of India which is alarming the radionuclide contamination in groundwater. Chronic ingestion can cause potential harm to humans and living things such as damage to kidney, cancer of liver, lungs, and bones. Present study to assess groundwater quality using multivariate approach and non-carcinogenic exposure of uranium in residents of district Bastar, Chhattisgarh. The concentration of uranium in groundwater samples was ranged from 0.50–26.4 μg/l in 70 samples, with 82% of samples being beyond the recommended limits of International Commission on Radiological Protection. Hierarchical cluster analysis is dividing all sampling locations into 10 clusters explaining similarity of geological condition. Factor analysis has extracted four principal components or factors with 70.20% cumulative variance from the entire data set. CDI has been found above from the reference dose in 34.29, 42.86, and 51.43% for young children, children and adults. The results of Hazard Quotient (HQ) classifying the degree of non-carcinogenic risk which was 34.28, 45.71, and 41.43% of the samples for young children, children and adults respectively. This study will generate base line data and suggest needs for revision of water quality monitoring plan and preventive water management practice.

Key words: chronic daily intake, cluster analysis, factor analysis, hazard quotient, risk assessment

HIGHLIGHTS

- The study was carried out in the Bastar division of Chhattisgarh, India.
- The concentration of uranium was found in the range from 0.50 to 26.40 μg/L.
- Total 58 groundwater samples were found to be higher concentrations of uranium than the ICRP recommended standard (1.9 μg/L).
- The chronic daily intake of uranium was observed to be higher in 24 samples for infants, 30 samples for children, and 36 samples for adults.

1. INTRODUCTION

Uranium is one of the techno-important radionuclide due to its radiological and chemical properties, and is found naturally in groundwater. Uranium dominates the Earth setting in all area of the environment such as the hydrosphere, lithosphere, atmosphere and biosphere (Duggal et al. 2017). Water chemistry plays an important role in the dissolution of uranium in groundwater. The mobility of uranium depends on an aqueous geochemical reaction; it’s highly soluble in alkaline, carbonate-containing water under oxidizing conditions, whereas it is less soluble in water under reducing and acidic condition (Cho & Choo 2019). Uranium is a radioactive metal that decays through alpha particle emission and contributes significantly after ingestion inside the body. 238U, 235U and 234U are isotopes commonly found in natural environments, while both 235U and 236U are the results of anthropogenic activities. 238U is contributing a maximum of 99.27% to the natural environment while 0.72 and 0.0054% for 235U and 236U (Smedley et al. 2006; Kumar et al. 2018a, 2018b). Its half-life is very long, which leads to bioaccumulation in all environmental matrices. The bioavailability of uranium depends on complexity by inorganic and organic legends, pH, absorption by soil and others minerals, hydroxide, interactions with organic matter, oxidation state...
etc. The +4 and +6 oxidation states of uranium are most soluble in aqueous environment that forms stable complexes with various ligands (Choppin et al. 2002; Coyte et al. 2018). The distribution of U (IV) is widespread in coffinite, uraninite and pitchblende uranium ores released under a reducing environment (Sar et al. 2017). U (IV) dissolves in the aqueous environment and forms complexes with inorganic ligands (uranyl phosphate and carbonate) and humic substances (uranyl humate and uranyl fulvate) (Choppin et al. 2002).

Surplus amounts of uranium are found in groundwater in different parts of the world due to natural and anthropogenic activities. Mining of uranium ore, nuclear testing, nuclear disposal site, phosphate fertilizer and laboratory uses are the largest sources of anthropogenic contamination of uranium in the environmental matrix (Alam & Cheng 2014; Nolan & Weber 2015; Guo et al. 2016; Kumar et al. 2020a, 2020b). Natural geochemical processes such as the dissolution of minerals and the desorption of adsorbed uranium from the surface of minerals can increasing the uranium contamination in groundwater which has dual effects on human body due to its radioactive and chemical properties. The World Health Organization (2011) and the United State Environmental Protection Agency (2011) set the guideline limit for maximum contamination levels of uranium in potable water at 30 μg/L. Ingestion, dermal adsorption and inhalation are common routes of entry radionuclides into the human body (Arogunjo et al. 2009). Uranium is also transferred to plants through the root system as nutrients and minerals as well as appearing in soil and irrigation water during growth and metabolic activity (Asaduzzaman et al. 2015).

The absorption of ingested uranium into the blood varies in the range of 0.1% to 6% (Kumar et al. 2018a, 2018b) and is deposited in the liver, kidneys and bones with the kidneys showing the highest chemical toxicity. The bone is the second most target of chemical poisoning in the human body. The absorption contribution of uranium in drinking water (85%) is higher than in other dietary or food ingredients (15%). Prolonged exposure to uranium poses a potential risk to human health (Thorne 2020). The chemical or carcinogenic health risk of uranium is more harmful than the radiological characteristics. Nephrotoxic effects, and chronic kidney disease are both associated with uranium-enriched drinking water; this was investigated in toxicological and epidemiological studies (Coyte et al. 2018). Chemical poisoning of uranium also causes damage to the reproductive systems and liver. Biologically dynamic toxicity, chemical toxicity and metabolism toxicity are several established health consequences of excessive ingested uranium, in addition to it; being noted for potential damage to gene expression, brain, and abnormal fetal development and embryonic and reproduction (Kaur & Mehra 2019) had gone. Atomic Energy Commission recommendation of a total daily intake 0.6 μg/kg/day of body weight with 100 as the uncertainty factor for calculating the low Observational adverse effect level (LOAEL) of 60 μg/kg of body weight per day the intake or reference dose was taken. Several studies on uranium contamination in potable water have been conducted in relation to risk assessment in different parts of India viz Bihar (Kumar et al. 2020a, 2020b), Punjab (Bajwa et al. 2017), Himachal Pradesh (Kaur & Mehra 2019), Jammu & Kashmir (Kumar et al. 2016), Jharkhand (Rana et al. 2010), as well as worldwide in Germany (Del Carmen Lamas 2005), USA (Nolan & Weber 2015), Korea (Cho & Choo 2019), Malaysia (Asaduzzaman et al. 2015), Nigeria (Arogunjo et al. 2009), the United Arab Emirates (Xiong et al. 2020), Canada (Chen 2018), and Australia (Priestley et al. 2018).

A review of the literature shows that uranium is widely available for exposure doses in different districts of the state of Chhattisgarh such as Durg (Sar et al. 2017), Bijapur (Singh et al. 2021), Balod (Sar et al. 2017), Bemetara (Sahu et al. 2019), Kanker (Sahu et al. 2020), but data is lacking or no such research has been conducted in Bastar district of Chhattisgarh State (India).

In recent years, many researchers have used principal components analysis (PCA) or factor analysis (FA) in understanding and grouping of water quality parameters (Kumar et al. 2020a, 2020b). Gajbhiye et al. 2015 used a PCA approach on two different sources of municipal waste (Moti Nala and Urdana Nala) in Jabalpur, India. Sahu et al. 2018 also used this method to identify seasonal variations in fluoride-contaminated groundwater quality of Lalganj tahsil, Raebareli district UP, India. According to environmental analysts, the factor analysis is more reliable than other statistical method which has no assumptions (Sahu et al. 2018). The purpose of FA is to reduce the number of variables to a manageable number of indices while maintaining relationships between real data sets.

The district Bastar is selected for this study because of 70 percentage population belong to tribal community and education percentage was very low (46% as per censuses 2011). 80% disease originated from ingestion of contaminated water and water quality monitoring is fist steps of water management plan. The main objective of proposed study is to evaluate groundwater quality with a multivariate approach and to assess the risk exposure to chemical toxicity of uranium through ignition of potable water by residents of District Bastar, Chhattisgarh (India). This study presented the physico-chemical parameters as pH,
alkalinity, TDS, hardness, Cl⁻, SO₄²⁻, NO₃⁻, PO₄³⁻ etc., with special reference to the multivariate approach, uranium concentration, correlation and non-carcinogenic risk of uranium and statistical approaches in the data set. The present investigation will generate baseline data for the study area which will help the policy maker of the state for make sound decision on managing water quality in present and future.

2. MATERIAL AND METHODS

2.1. Study area
Bastar is a district located in the central Indian state of Chhattisgarh as presented in (Figure 1). It is situated between 19.5676 North Latitudes and 81.6912 East Longitudes. Jagdalpur is the district headquarters of Bastar and is surrounded by Nabarangpur and Koraput districts of Odisha state to the east, Narayanpur district to the northwest, Kondagaon district to the north and Dantewada and Sukma to the south. According to the census report, the total population of a district is 8,34,873 people, living in a total area of 6,597 square kilometer. Geologically, the district is covered with gneiss, granite, meta-sedimentary, basalt and gabbroic rocks and the landscape is dominated by dense forest, with half the district being mountainous and rocky. The soil of the district has a wide variety such as loam, alfisol, red gravel and red sandy, they are the soils that cover most of the area. The Indravati river system, along with the Markandi and Narangi rivers, serves as the main drainage system of the district. The Indravati River and the Sabari River, both tributaries of the Godavari River, cover about 97 percent of the area in this region. The average annual rainfall of the district is 1,386.77 mm. The annual temperature ranges from 10.6 °C in the winter to 46 °C in summer. The relative humidity ranges from 90% in the wet season to 30% to 40% in the winter season.

2.2. Sample collection
70 groundwater samples were taken from hand pumps at different places in Bastar district and sampling was carried out during the period of April 2019, water sample was drawn for drinking purpose by the local population. All samples were collected in pre washed polypropylene bottles after 5 min of hand pumping and washing, three times from the respective samples. The polypropylene bottles are air-tight lab-grade in nature, with a 2 liter capacity, that have been infused with 10% nitric acid overnight to eliminate grime on the inner surface of the container. 0.45-μm Whatman filter paper was used to filter all water samples prior to analysis. APHA (American Public Health Association) standard protocols were followed for the special storage, handling and transportation of water samples. (APHA 2005)

2.3. Analysis of physicochemical parameters
For the purpose of analysis, all water samples were brought to the Department of Chemistry, National Institute of Technology, Raipur, India. Seventeen water quality parameters were examined, most in accordance with a series of (WHO 2008) and (IS 3025) drinking water analysis manuals. *In situ* parameters such as TDS (total dissolved solids), EC (electrical conductivity), pH, temperature, oxidation-reduction potential (ORP), salinity, and DO (dissolved oxygen) were tested using the Hanna instrument (HI 98194) at the time of sampling. The Total hardness in water samples with calcium hardness as CaCO₃ was calculated via the EDTA complexometric method accomplished using Eriochrome Black T and Murexide indicators, respectively. Further magnesium hardness was calculated by subtracting the calcium hardness from the total hardness. A standardized solution of 0.02 N of H₂SO₄ and a methyl orange indicator was used to estimate the total alkalinity in the water sample, and Mohr’s titration method has been used to calculate the chloride ions in the groundwater sample. The technique used for nitrate analysis was a UV-Vis Spectrophotometer (UV – 1800, Shimadzu, Kyoto, Japan) using 1 N HCl at 220 and 275 nm. Conditioning reagent (NaCl+HCl+Alcohol+Glycerol) and BaCl₂ were used to determine the amount of sulphate in the sample. The absorbance of the turbid solution was measured after 2–3 minutes at 420 nm wavelength. For Phosphate measurement color was developed by addition of 10% ascorbic acid, and mixed reagent i.e. 125 ml 10% ammonium molybdate + 9N H₂SO₄ + 2.5% potassium antimony tartarate. Absorbance was taken after through mixing for 10 minutes after the development of blue colour at 690 nm, (APHA 2005).

2.4. Uranium measurement in groundwater
Uranium in drinking water was tested using LF-2a LED fluorimeter manufactured by Quantalase Enterprises Pvt. Ltd Indore, India. The minimum and highest detection limits of the device are 0.2 μg/L and 1,000 μg/L, respectively, with a ±10% precision. The buffer solution sodium pyrophosphate (5%) was prepared in Milli-Q water and the orthophosphoric acid was

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used to adjust drop by drop to pH 7. This solution acts as a fluorescence enhancer. The fluorescence yields for the different uranium complexes varied greatly. Therefore, a reagent i.e. fluorescence-enhancing solution was added to the sample to ensure a uniform conversion of fluorescence yield for all the complexes in the same manner. A 5.0 ml water sample was
placed in a cuvette and 0.5 ml of 5% sodium pyrophosphate was added, and the uranium concentration was determined using an LED fluorimeter. (Singh et al. 2021).

2.5. Quality control and quality assurance
Analytical research-grade (AR) chemicals (Merck and Sigma – Aldrich, Germany) were used throughout the research work. There was no further purification or disturbance to them. The glass wares were first cleaned with dilute (HNO₃) nitric acid (1.15 N) and then; it was washed with distilled water. Mili-Q water was used to make all reagent and calibration standards for analysis. All analyzes were performed in triplicate. In addition, all reference and stock solutions were kept at 4 °C until they were used in the analysis. As a part of quality assurance, rigorous washing/cleaning procedures as well as monitoring of blank levels of equipment, solvents and other items were ensured.

2.6. Statistical analysis
Multivariate statistical analysis such as factor analysis, cluster analysis and spearman correlation etc. were selected to analyze the huge datasets generated from 70 sampling locations. All the statistical analysis were runs in SPSS software (version 22) to inspect the associations among multiple variables in the Physico-chemical data set of groundwater. Varimax with Kaiser Normalization method was used to interpret the major factors contributing to the decline in water quality. Cluster analysis such as the Rascal distance method was applied to determine how close two samples are and physico-chemical parameters while the Rascal distance is defined as the difference between the transformed values of the samples. Spearman correlation analysis was performed in two ways at 0.05 and 0.01 level of α to identify the correlation between physico-chemical parameters.

2.7. Non carcinogenic risk assessment
Hazards quotients (HQ) indicate the level of harm caused by consuming uranium-contaminated water; HQ was used to measure chemical risk, which was calculated using Equation (1), and chronic daily intake, which was calculated using Equation (2) (Singh et al. 2021).

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HQ = \frac{CDI}{RfD}
\]

\[
CDI = \frac{CDw \times IR \times ED \times EF}{AT \times BW}
\]

where CDI is refereed for chronic daily intake (μg/kg/day), RDF denotes the reference dose of uranium (0.6 μg/kg/day), CDw=concentration of uranium in drinking water (μ/L), IR=drinking water ingestion rate in L/day, ED=exposure duration in year for different classified age groups (4, 12, and 30 years for young children, children, and adults respectively), EF=Exposure frequency 365 days in year, AT=average time (days) and BW=body weight in kg.

The ingestion rate and body weight were assessed through a random survey of residents in the research area. IR was 6, 3, and 1 L for adults, children, and young children respectively. BW was 60, 40, and 14 kg for the same age groups (Singh et al. 2021). Total 300 inhabitants involved individually through the random survey for the ingestion study, they haven’t filter/treated water system.

3. RESULT AND DISCUSSION

3.1. Evaluation for drinking water quality
Seventeen Physico-chemical parameters of groundwater collected from 70 locations of district Bastar were analyzed (Table 1). The groundwater of the study area is found to be slightly acidic in nature. The pH values of the water samples ranged from 5.2 to 8.2 with an average of 6.74 ± 0.08. This was under the prescribed drinking water standard (6.5–8.5) of Bureau of Indian Standards (BIS 10500) and World Health Organization (WHO 2011). According to the World Health Organization, 8.5 pH water has no apparent effect on users (WHO 2011). Consuming drinking water containing high levels of TDS may result in gastrointestinal pain that consumer’s experience (Sahu et al. 2018). The total dissolved solids in groundwater samples ranges from 96 to 389 mg/L, which is the TDS limit for groundwater samples found to be below the WHO recommended value. Industrial wastewater, natural sources, sewage, urban and agricultural runoff, all contributes to the total dissolved solids in groundwater (Duggal et al. 2021). The groundwater temperature ranged from 27.80 to 32.80 °C.
and the groundwater was extracted from 80 to 330 feet below the surface. The electrical conductivity of the water samples analyzed ranged from 192 to 778 \( \mu \text{S/cm} \) and oxidation redox potential was \(-94.60\) to \(96.10\) mV. The presence of dissolution of minerals and electrolytes might contribute the higher electrical conductivity. The high chloride content in drinking water gives it a salty taste and can also cause constipation (Rao 2006). The chloride, salinity and phosphate concentration in the groundwater samples of the study area ranged from 16 to 80, 80 to 380 and 0.10 to 0.14 mg/l. Total hardness is measured in Ca\(^{2+}\) and Mg\(^{2+}\) concentrations and is usually expressed as CaCO\(_3\). The key parameters for total hardness are calcium (Ca\(^{2+}\)) and magnesium (Mg\(^{2+}\)) from 26 to 236 mg/L and 12 to 96 mg/L, respectively. Sedimentary rocks are the most common natural source of hardness in groundwater. Groundwater may dissolve CaCO\(_3\) during infiltration or along with the flow, CaCO\(_3\) and Mg(CO\(_3\))\(_2\) present in the rocks will enhance the concentration of calcium ions in groundwater. Hard water is usually found in area with dense topsoil and limestone formation. The total hardness concentration in the research area was found to be between 40 and 288 mg/L. The total hardness value of water samples is well below the recommended limit (WHO 2011). The sum of carbonate and bicarbonate indicates total alkalinity, and carbonate was not found in groundwater belonging to this research area. According to the World Health Organization, the appropriate range of total alkalinity in drinking water is \(200–600\) mg/L. The alkalinity in the groundwater samples of Bastar district ranged from 24 to 214 mg/L.

### 3.2. The concentration of uranium in groundwater

The concentration of uranium in the water samples was measured in the range of 0.50 to 26.4 \(\mu\)g/L with an average of 6.96 \(\mu\)g/l (Figure 2). For the sake of humanity, environmental protection organizations have set a safe limit value for uranium concentration in drinking water. According to the International Commission on Radiological Protection (ICRP), the safe limit

| Parameters          | Unit      | Minimum | Maximum | Mean    | SEM    | BIS/WHO Limits |
|---------------------|-----------|---------|---------|---------|--------|----------------|
| Depth level         | Feet      | 80.0    | 330.0   | 201.43  | 8.07   | –              |
| Gamma Radiation     | nSv/h     | 98.0    | 256.0   | 155.16  | 5.47   | –              |
| pH                  |           | –       | 5.20    | 8.20    | 6.74   | 0.08 (6.5–8.5) |
| TDS                 | mg/L      | 96.0    | 389.0   | 229.57  | 9.03   | 500–2000       |
| EC                  | \(\mu\text{S/cm}\) | 192.0 | 778.0   | 459.14  | 18.06  | –              |
| ORP                 | \(\pm\text{mV}\)  | –94.6   | 96.1    | 20.61   | 5.37   | –200 +200      |
| Temperature         | °C        | 27.8    | 32.8    | 29.85   | 0.13   | –              |
| Salinity            | mg/L      | 80.0    | 380.0   | 216     | 8.99   | –              |
| DO                  | mg/L      | 2.1     | 5.4     | 3.8     | 0.1    | –              |
| Chloride            | mg/L      | 16.0    | 80.0    | 40.59   | 1.57   | 250            |
| Nitrate             | mg/L      | 2.30    | 28.0    | 11.72   | 0.67   | 45             |
| Sulphate            | mg/L      | 2.60    | 34.2    | 9.44    | 0.65   | 200–400        |
| Phosphate           | mg/L      | 0.1     | 0.14    | 0.1     | 0      | –              |
| Uranium             | \(\mu\text{g/L}\) | 0.50  | 26.4    | 6.97    | 0.6    | 1.9*           |
| Total hardness      | mg/L      | 40.0    | 288.0   | 149.59  | 7.31   | 200–600        |
| Ca Hardness         | mg/L      | 26.0    | 236.0   | 104.83  | 5.87   | 75–200         |
| Mg Hardness         | mg/L      | 12.0    | 96.0    | 44.76   | 2.2    | 30–100         |
| Total Alkalinity    | mg/L      | 24.0    | 214.0   | 115.43  | 5.79   | 200–600        |

*SEM Standard Error Mean, Total Hardness, Ca Hardness and Mg Hardness was calculated as CaCO\(_3\). *Standard guideline for Uranium in drinking water as per International Commission on Radiological protection.
for uranium in drinking water is 1.9 micrograms per liter (ICRP 1979). 58 groundwater samples were found to exceed the permissible level set by the International Commission on Radiological Protection (ICRP) (Figure 3). The uranium in groundwater release from natural origin or uranium containing minerals such as coffinite and pitchblende have found in geology of the Indrâvati basin (Kumar et al. 2018a, 2018b). Consumption of uranium-contaminated water for drinking purpose can be harmful to human health. The major targets of action of uranium are the kidneys, liver and bones (Sar et al. 2017).

3.3. Factor analysis

Factor analysis is usually normalized to physico-chemical data and eliminate misclassification due to the different range of variance and the order of magnitude of the analytical parameters. Factor analysis collects the data and describes variables with drawing clear conclusions about the correlation between variable (physico-chemical parameters) and factors. The rotation of the factors was performed by Varimax with Kaiser Normalization. This analysis is used to extrapolate the computational pattern between 17 physico-chemical parameters and explaining the sources of affecting water quality. Four factor were yield with >1 Eigen value from 16 physicochemical parameters were given in (Table 2) and Figure 4(a) and 4(b). The rotation sums of the square loadings measuring the degree of closeness between the variables and the values of the factor or PCs presented in the Table 3. Both positive and negative loadings are used in factor loading. A weak correlation is indicated by a loading between 0 and ±0.49, while a loading between ±0.5 and ±0.74 indicates a moderate correlation, is a loading greater than ±0.75 indicates a strong correlation and a loading closer to ±1 point towards the highest correlation.

**Figure 2** | Tahsil wise comparatively demonstration of uranium in groundwater of Bastar district.

**Figure 3** | Comparatively demonstration of concentration of uranium with standard of various International regulatory organizations.
Table 2 | Total variance explained in Factor analysis for Physico-chemical variables of groundwater of Bastar district

| Component | Initial Eigen values | Extraction Sums of Squared Loadings | Rotation Sums of Squared Loadings |
|-----------|----------------------|-------------------------------------|----------------------------------|
|           | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1         | 7.21  | 40.054        | 40.054       | 7.21  | 40.054        | 40.054       | 7.176 | 39.864        | 39.864       |
| 2         | 2.509 | 13.936        | 53.99        | 2.509 | 13.936        | 53.99        | 2.316 | 12.864        | 52.729       |
| 3         | 1.499 | 8.328         | 62.318       | 1.499 | 8.328         | 62.318       | 1.647 | 9.15          | 61.879       |
| 4         | 1.419 | 7.883         | 70.201       | 1.419 | 7.883         | 7.883        | 1.498 | 8.322         | 70.201       |

Figure 4 | Screen Plot and Component Plot in Rotated Space for factor analysis.
Table 3 | Rotated component matrix of Factor analysis for Physico-chemical variables of groundwater of Bastar district

Rotated Component Matrix*

| Component | Depth Level | Gamma Radiation | pH | TDS | EC | ORP | Temp. | Salinity | DO | Cl⁻ | NO₂⁻ | SO₄²⁻ | PO₄³⁻ | U | TH | CaH | MgH | TA |
|-----------|-------------|-----------------|----|-----|----|-----|-------|----------|----|-----|------|-------|-------|----|----|-----|-----|----|
| 1         | -0.324      | -0.035          | 0.451 | 0.976 | 0.976 | 0.005 | 0.05 | 0.974 | 0.148 | 0.818 | 0.088 | 0.190 | -0.127 | -0.078 | 0.973 | 0.956 | 0.731 | 0.947 |
| 2         | 0.379       | -0.035          | -0.277 | -0.035 | -0.035 | 0.040 | 0.101 | -0.037 | -0.333 | 0.406 | 0.867 | 0.394 | 0.306 | 0.888 | 0.028 | 0.065 | -0.082 | 0.040 |
| 3         | 0.573       | **0.795**       | -0.176 | 0.028 | 0.028 | -0.660 | 0.229 | 0.022 | -0.212 | -0.046 | -0.015 | 0.316 | -0.006 | -0.066 | -0.064 | -0.065 | -0.038 | -0.064 |
| 4         | -0.173      | -0.018          | -0.059 | -0.026 | -0.026 | -0.198 | 0.777 | -0.010 | 0.471 | -0.123 | 0.122 | -0.085 | **0.683** | 0.182 | 0.046 | -0.032 | 0.238 | 0.044 |

Extraction Method: Principal Component Analysis.

Rotation converged in 6 iterations. Rotation Method: Varimax with Kaiser Normalization.

0-0.49 Weak loading, 0.50-0.74 moderate loading, 0.75-0.95 strong loading, >1 highest loading (Sahu et al. 2018).
(Sahu et al. 2018). Factor analysis 1 accounts for 39.864% variance of the total cumulative variance; it has the highest loading with Total Dissolved Solid, Electrical Conductivity, Salinity, and Total Hardness while Chloride, Calcium Hardness, and Total Alkalinity contributed to strong loadings. Only Magnesium hardness contributed to moderate loadings at Factor 1. This factor are explaining the mineralization process in groundwater due to calcium and magnesium hardness. The same trends in also observed in the groundwater of dongergaon block (Sahu et al. 2017). Factor analysis 2 holds a 12.864% variance of the total cumulative variance does not have the highest loading, but, both uranium and nitrate contributes to strong loading. The uranium contains in groundwater due to natural occurrences of uranium ore deposited in the bed rock of the aquifer. The highest loading of uranium and nitrate in the factor 2 suggesting that dissolution from uranium minerals such as uranyl nitrate (UO2(NO3)2) (Saikia et al. 2021) also found the similar trends between uranium and nitrate in the groundwater of Nalbari district of Assam. Factor analysis 3 has 9.150% variance of the total cumulative variance and shows strong loading with Gama radiation while Depth Level contributed to moderate loading suggesting deep bedrock of the aquifer loaded with significance amount of radioactive element. The physico-chemical parameter did not show the highest loading in Factor 4 but the only temperature contributed to the strong loading whereas moderate loading with phosphate and Factor 4 has 8.322% variance of the total cumulative variance 70.201. The temperature is the most important parameter that influence the water chemistry. Factor 4 signifying that the groundwater temperature playing significance role in mineralization increasing with rising the temperature.

3.4. Spearman’s correlation matrix

To determine the relationship between the physico-chemical parameters, Spearman’s correlation matrix (a two-tailed) was run at 0.01 and 0.05 level of significance data mining strategy that divides variables into groups on the similarity and differences within each category. Classification of physicochemical variables was performed using cluster analysis. Ward’s Linkage method was applied to calculate the similarity of physico-chemical data and the results provided visually meaningful dendrogram and differentiated groups. The dendrogram classified the eighteen variables into six broad classes, each of which was further subdivided into smaller clusters, as seen (Figure 5(a)). The entire Physico-chemical parameter was dividing into 2 macro-clusters, which show the maximum distance of 25 scales in the Rescale Distance Cluster Combined Scale. Cluster 1 is further divided into two micro-clusters, pH, DO, PO4−3, NO3−, and Uranium in micro-cluster 1.1 and SO4−2, Cl−, magnesium hardness, temperature, and ORP included in mini-cluster 1.2. Macro-cluster 2 is further divided into two micro-clusters with a disparity level 13 scale in which EC contributes to micro-cluster 2.2, while micro-cluster 2.1 again splits into three mini-clusters containing TDS and salinity show similarity and form mini-cluster 2.1.1. The second mini-cluster 2.1.2 was showing similarity between group, Calcium hardness, Total alkalinity, and total hardness while depth and Gamma radiation contribute to mini-cluster 2.1.3. Cluster analysis was also used by Sahu et al. (2018), to classify the physicochemical variable of groundwater samples.

Ward’s Linkage method was also applied to calculate the level of similarity in the concentration of uranium released from the geology of the respective groundwater sampling location presented in (Figure 5(b)) providing visually meaningful dendrogram, which colonized all 70 sampling locus into 10 sub-clusters. Sub-clusters 1 to 8 are minor branches of cluster 1 while sub-cluster 9 and 10 are both major benches of cluster 2. The dissolution of uranium in groundwater was similar within the groups/clusters while dissimilarity is measured between groups/ clusters measured as rescaled distance cluster combine scale present in (Figure 5(b)).

3.6. Non-carcinogenic risk assessment

Non-carcinogenic risk was determined by analyzing chronic daily intake by potable water and uranium concentration in drinking water for different age groups (young children, children, and adults) of residents living in the study region. (Figure 6) compares the reference doses (RID) with the analyzed chronic daily intake (CDI) value for young children, children and adult residents in Bastar district and (Figure 7) compares the recommended hazard quotients (HQ) does with the analyzed hazard
Table 4 | Spearman’s correlation coefficient within Physicochemical parameters of Bastar district (n=70)

| Parameter  | DL (Feet) | GR (nS/ cm) | pH | TDS (mg/l) | EC (μS/cm) | ORP (mV) | Temp. (°C) | Salinity (mg/l) | DO (mg/l) | Cl⁻ (mg/l) | NO₃⁻ (mg/l) | SO₄²⁻ (mg/l) | PO₄³⁻ (mg/l) | U (μg/l) | TH (mg/l) | CaH (mg/l) | MgH (mg/l) | TA (mg/l) |
|------------|-----------|-------------|----|------------|-------------|----------|-----------|----------------|-----------|-------------|-------------|--------------|--------------|------------|-----------|-------------|-------------|-------------|----------|
| Depth level | 1         |             |    |            |             |          |           |                 |           |             |             |              |              |            |           |             |             |             |          |
| Gamma radiation | 0.384ᵇ | 1 | | | | | | | | | | | | | | | | | | |
| pH         | −0.317    | −0.033     | 1  | 0.401ᵇ     | 1           |          |           |                 |           |             |             |              |              |            |           |             |             |             |          |
| TDS        | −0.279    | −0.031     | 0.401ᵇ | 1 |          |           |          |                 |           |             |             |              |              |            |           |             |             |             |          |
| EC         | −0.279    | −0.031     | 0.401ᵇ | 1 | 1        |           |          |                 |           |             |             |              |              |            |           |             |             |             |          |
| ORP        | −0.181    | −0.277     | 0.099 | 0.011 | 0.111  | 1         |           |                 |           |             |             |              |              |            |           |             |             |             |          |
| Temp.      | −0.070    | 0.134      | −0.064 | 0.032 | 0.032   | −0.211  | 1         |                 |           |             |             |              |              |            |           |             |             |             |          |
| Salinity   | −0.284    | −0.040     | 0.401ᵇ | 0.099ᵇ | 0.999ᵇ | 0.005   | 0.038    | 1             |           |             |             |              |              |            |           |             |             |             |          |
| DO         | −0.218    | −0.115     | 0.153 | 0.143 | 0.077  | 0.138   | 0.151    | 1             |           |             |             |              |              |            |           |             |             |             |          |
| Cl⁻        | −0.139    | −0.039     | 0.319ᵃ | 0.788ᵇ | 0.788ᵇ | 0.058   | 0.015    | 0.783ᵇ       | −0.036    | 1           |             |              |              |            |           |             |             |             |          |
| NO₃⁻       | 0.225     | 0.057      | −0.111 | 0.030 | 0.030   | −0.043  | 0.163    | 0.029         | −0.096    | 0.447ᵇ     | 1           |              |              |            |           |             |             |             |          |
| SO₄²⁻      | 0.237ᵃ | 0.097      | −0.089 | 0.169 | 0.169   | −0.046  | 0.128    | 0.160         | −0.056    | 0.224ᵃ     | 0.182       | 1             |              |            |           |             |             |             |          |
| PO₄³⁻      | 0.348ᵃ | 0.207      | −0.056 | 0.084 | 0.084   | 0.165   | 0.002    | 0.078         | −0.054    | 0.107      | 0.160       | 0.149         | 1             |            |           |             |             |             |          |
| U          | 0.212ᵃ | −0.059     | −0.182 | −0.121 | −0.121  | −0.054  | 0.205    | −0.117        | −0.215    | 0.259ᵃ     | 0.748ᵇ      | 0.263ᵇ       | 0.070         | 1             |           |             |             |             |             |          |
| TH         | −0.338    | −0.088     | 0.375ᵇ | 0.920ᵇ | 0.920ᵇ | 0.037   | 0.048    | 0.918ᵇ       | 0.159     | 0.768ᵇ     | 0.112       | 0.154         | 0.071         | −0.050       | 1             |             |             |             |             |          |
| CaH        | −0.290    | −0.091     | 0.334ᵃ | 0.899ᵇ | 0.899ᵇ | 0.046   | 0.001    | 0.892ᵇ       | 0.172     | 0.769ᵇ     | 0.153       | 0.159         | 0.072         | −0.047       | 0.967ᵇ       | 1             |             |             |             |          |
| MgH        | −0.346    | −0.049     | 0.354ᵇ | 0.638ᵇ | 0.658ᵇ | 0.001   | 0.155    | 0.666ᵇ       | 0.069     | 0.499ᵇ     | −0.037      | 0.085         | 0.045         | −0.040       | 0.738ᵇ      | 0.543ᵇ       | 1             |             |             |             |          |
| TA         | −0.304    | −0.103     | 0.353ᵇ | 0.894ᵇ | 0.894ᵇ | 0.034   | 0.031    | 0.891ᵇ       | 0.139     | 0.723ᵇ     | 0.117       | 0.150         | 0.083         | −0.040       | 0.969ᵇ      | 0.934ᵇ      | 0.722ᵇ       | 1             |             |             |          |

0-0.49 weak correlation, 0.5-0.74 moderate positive correlation, >0.75 strong correlation, -1 highest correlation (Singh et al. 2021). Correlation is significant (a) at the 0.05 level and (b) at the 0.01 level.
The observed CDI values for young children, children, and adults in District Bastar ranged from 0.04 to 1.89 with an average of 0.50 for young children, 0.04 to 1.98 with an average of 0.52 for children, and 0.05 to 2.64 with an average of 0.70 for adults shown in (Table 5), respectively. The assessed value of the CDI has been found to exceed the reference dose in 24 samples for young children, 30 samples for children, and 36 samples for adults. WHO has suggested that a maximum of 0.6 μg/kg/day uranium may be acceptable, beyond the recommended values that would pose potential health risks to humans and other living beings, such as gene mutations, defects in developing fetuses and infants etc. Numerous researchers also conducted uranium exposure risk assessments in

**Figure 5** | Dendrograms or tree plot of cluster analysis for Physico-chemical variables 5 (a) and Samples wise 5 (b).
Figure 6 | Comparatively demonstration of Chronic Daily Intake of uranium, recommended reference dose and Hazardous Quotient for different age grouped of inhabitant of Bastar district.

Figure 7 | Comparatively demonstration of Hazardous Quotient and for different age grouped of inhabitant of Bastar district.

Table 5 | CDI and HQ values for non-carcinogenic risk assessment in different age groups of inhabitants of district Bastar

| District | Age Group | Statistics | Intake Rate (Liter) | Exposure Duration (year) | Exposure Frequency (Day) | Body Weight (Kg) | Average Time (Day) | Reference Dose (μg/kg/day) | U level in GW (μg/l) | U CDI (μg/kg/day) | Hazard Quotient |
|----------|-----------|------------|---------------------|--------------------------|--------------------------|-----------------|-------------------|--------------------------|----------------|----------------|----------------|
| Bastar   | Young     | Mean       | 1                   | 4                        | 365                      | 14              | 1,460             | 0.6                      | 6.97           | 0.5            | 0.83           |
|          |           | Min        | 1                   | 4                        | 365                      | 14              | 1,460             | 0.6                      | 0.5            | 0.04          | 0.06          |
|          |           | Max        | 1                   | 4                        | 365                      | 14              | 1,460             | 0.6                      | 26.4           | 1.89          | 3.14          |
|          | Children  | Mean       | 3                   | 12                       | 365                      | 40              | 4,380             | 0.6                      | 6.97           | 0.52          | 0.87          |
|          |           | Min        | 3                   | 12                       | 365                      | 40              | 4,380             | 0.6                      | 0.5            | 0.04          | 0.06          |
|          |           | Max        | 3                   | 12                       | 365                      | 40              | 4,380             | 0.6                      | 26.4           | 1.98          | 3.3           |
|          | (3–6 year)| Mean       | 6                   | 30                       | 365                      | 60              | 10,950            | 0.6                      | 6.97           | 0.7           | 1.16          |
|          |           | Min        | 6                   | 30                       | 365                      | 60              | 10,950            | 0.6                      | 0.5            | 0.05          | 0.08          |
|          |           | Max        | 6                   | 30                       | 365                      | 60              | 10,950            | 0.6                      | 26.4           | 2.64          | 4.4           |
different parts of Chhattisgarh (Sar et al. 2018; Sahu et al. 2019; Singh et al. 2021). CDI was previously studied by Singh et al. in district Bijapur 2021, ranged from 0.03 to 1.67, which is the lowest in comparison to the present study.

HQ values for young children, children and adults in the study area ranged from 0.06 to 3.14 with an average of 0.83 for young children, 0.06 to 3.30 with an average of 0.87 for children, and 0.08 to 4.40 with an average of 1.16 for adults. The measured values of HQ in 24 water samples for young children were found to exceed the recommended value of HQ in 32 water samples for children and 36 water samples for adults, if the HQ is exceeded the recommended value of 1, which indicating a significant possibility of chemical toxicity (WHO 2008). HQ in district Bemetara was previously studied by Sahu et al. (2019), ranged from 0.04 to 6.04 which are higher as compare to our study. Uranium risk assessment studies were also conducted in several districts of Chhattisgarh state such as Durg, Balod, Bemetara, Kanker but there was no population difference in different age groups and lack of data or no such research in Bastar district of Chhattisgarh state has gone (Sar et al. 2017; Sahu et al. 2019; Sahu et al. 2020).

4. CONCLUSION

The objective of this study was accomplished to assess the quality and health risks of uranium-rich groundwater by ingestion of uranium through drinking water in age groups of residents of district Bastar, Chhattisgarh, Central India. A total of 58 groundwater samples in the district were found to have high concentrations of uranium in excess of standard (1.9 μg/L), recommended by the International Commission on Radiological Protection, which may be a cause for concern. Uranium shows a significant affinity with nitrate, chloride and sulfate ions. The measured concentration of pH, TDS, salinity, total hardness, magnesium hardness, total alkalinity, Cl⁻, NO₃⁻, SO₄²⁻, and, PO₄³⁻ were well within the drinking water standards of WHO and BIS, but it is observed for calcium hardness concentration, exceeds WHO and BIS drinking water standard. The factor analysis calculated four factors in the seventeen groundwater parameters extracting 70.201% of the cumulative variance in the data set. Cluster analysis was successfully performed with better results for uranium releasing nature in the geology of the district across all sampling locations. The chronic daily intake of uranium from drinking water was found to exceed the reference value. The hazard quotient (HQ) was found to be >1 for young children, children, and adults. ‘The study strongly suggesting for vital consideration for study on temporal variation and adopt preventive action or installed remedial technologies in the prone area’.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

Alam, M. S. & Cheng, T. 2014 Uranium release from sediment to groundwater: influence of water chemistry and insights into release mechanisms. Journal of Contaminant Hydrology 164, 72–87. doi.org/10.1016/j.jconhyd.2014.06.001.

APHA (American Public Health Association) 2005 Standard Methods for the Examination of Water and Wastewater. Washington DC, USA.

Arogunjo, A., Hollriegl, V., Giussani, A., Leopold, K., Gerstmann, U., Veronese, I. & Oeh, U. 2009 Uranium and thorium in soils, mineral sands, water and food samples in a tin mining area in Nigeria with elevated activity. Journal of Environmental Radioactivity 100 (3), 232–240. doi.org/10.1016/j.jenvrad.2008.12.004.

Asaduzzaman, K., Khandaker, M. U., Amin, Y. M. & Mahat, R. 2015 Uptake and distribution of natural radioactivity in rice from soil in north and west part of peninsular Malaysia for the estimation of ingestion dose to man. Annals of Nuclear Energy 76, 85–93. doi.org/10.1016/j.anucene.2014.09.036.

Bajwa, B. S., Kumar, S., Singh, S., Sahoo, S. K. & Tripathi, R. M. 2017 Uranium and other heavy toxic elements distribution in the drinking water samples of SW-Punjab, India. Journal of Radiation Research and Applied Sciences 10 (1), 13–19. doi.org/10.1016/j.jrras.2015.01.002.
Balbudhe, A. Y., Srivastava, S. K., Vishwaprasad, K., Srivastava, G. K., Tripathi, R. M. & Puranik, V. D. 2012 Assessment of age-dependent uranium intake due to drinking water in Hyderabad, India. *Radiation Protection Dosimetry* **148** (4), 502–506. doi.org/10.1093/rpd/nct193.

Chen, J. 2018 A summary of natural radionuclides in Canadian public water supply systems. *Radiation Environment Medicine* **7**, 9–11.

Cho, B. W. & Choo, C. O. 2019 Geochemical behavior of uranium and radon in groundwater of Jurassic granite area, Icheon Middle Korea. *Water* **11** (6), 1278. doi.org/10.3390/w11061278.

Choppin, G., Liljenzin, J. O. & Rydberg, J. 2002 Behavior of Radionuclides in the Environment. *Radiochemistry and Nuclear Chemistry*, 3rd ed. Butterworth-Heinemann, London, pp. 653–685.

Coyte, R. M., Jain, R. C., Srivastava, S. K., Sharma, K. C., Khalil, A., Ma, L. & Vengosh, A. 2018 Large-scale uranium contamination of groundwater resources in India. *Environmental Science & Technology Letters* **5** (6), 341–347. doi.org/10.1021/acs.estlett.8b00215.

Del Carmen Lamas, M. 2005 Factors Affecting the Availability of Uranium in Soils. Federal Agricultural Research Centre, Braunschweig, Germany. Available from: https://literatur.thuenen.de/digbib_EXTERN/bitv/zi036810.pdf. ISSN 0376-0723.

Duggal, V., Sharma, S., Saini, K. & Bajwa, B. S. 2017 Assessment of carcinogenic and non-carcinogenic risk from exposure to Uranium in groundwater from Western Haryana, India. *Journal of the Geological Society of India* **89** (6), 663–668. doi.org/10.1007/s12594-017-0675-y.

Duggal, V., Sharma, S. & Singh, A. 2021 Risk assessment of uranium in drinking water in Hisar district of Haryana, India. *Water Supply* **21**(1), 249–261. doi.org/10.2166/ws.2020.313.

Gajbhiye, S., Sharma, S. K. & Awasthi, M. K. 2015 Application of principal components analysis for interpretation and grouping of water quality parameters. *International Journal of Hybrid Information Technology* **8**(4), 89–96. doi.org/10.14257/ijhit.2015.8.4.11.

Guo, H., Jia, Y., Wanty, R. B., Jiang, Y., Zhao, W., Xiu, W., Shen, J., Li, Y., Cao, Y., Wu, Y. & Zhang, D. 2016 Contrasting distributions of groundwater arsenic and uranium in the Western Hetao Basin, Inner Mongolia: implication for origins and fate controls. *Science of the Total Environment* **541**, 1172–1190. doi.org/10.1016/j.scitotenv.2015.10.018.

ICRP-30 (International Commission on Radiological Protection) 1979 Limits for Intake of Radionuclides by Workers. Pergamon Press, Oxford, UK.

IS (Indian Standard) 2012 *Guidelines for Drinking Water*. Bureau of Indian Standard (BIS: 10500) Second Revision. Available from: http://cgwb.gov.in/Documents/WQ-standard-ards.pdf.

Kansal, S., Mehra, R. & Singh, N. P. 2011 Uranium concentration in ground water samples belonging to some areas of Western Haryana, India using fission track registration technique. *Journal of Public Health and Epidemiology* **3**(8), 352–357. ISSN 2141-2316.

Kaur, S. & Mehra, R. 2019 Toxicological risk assessment of protracted ingestion of uranium in groundwater. *Environmental Geochemistry and Health* **41**(2), 681–698. doi.org/10.1007/s10653-018-0162-4.

Kumar, A., Kaur, M., Mehra, R., Sharma, S., Mishra, R., Singh, K. P. & Bajwa, B. S. 2016 Quantification and assessment of health risk due to ingestion of uranium in groundwater of Jammu district, Jammu & Kashmir, India. *Journal of Radioanalytical and Nuclear Chemistry* **310**(2), 793–804. doi.org/10.1007/s10967-016-4933-z.

Kumar, D., Singh, A. & Jha, R. K. 2018a Spatial distribution of uranium and basic water quality parameter in thecbil and consequent ingestion dose. *Environmental Science and Pollution Research* **25**(18), 17901–179014. doi.org/10.1007/s11356-018-1922-5.

Kumar, K., Banerjee, R. & Malpe, D. B. 2018b Geochemistry and uranium potential of tirathgarh formation, Indravati basin, bastar district, chhattisgarh, india. *Journal of Applied Geochemistry* **20**(4), 392–398.

Kumar, D., Singh, A., Kumar, P., Jha, R. K., Sahoo, S. K. & Jha, V. 2020b Sobol sensitivity analysis for risk assessment of uranium in groundwater. *Environmental Geochemistry and Health*. 1–13. doi.org/10.1007/s10653-020-00522-5.

Kumar, V., Sahu, P. & Singh, P. K. 2020a Multivariate statistical approach for the organic and inorganic pollutants in diverse location of Gomti river at Lucknow City. *International Journal of Environmental Research* doi.org/10.1007/s14174-020-00290-1.

Nolan, J. & Weber, K. A. 2015 Natural uranium contamination in major U.S. Aquifers linked to nitrates. *Environmental Science & Technology Letters* **2**(8), 215–220. doi.org/10.1021/acs.estlett.5b00174.

Priestley, S. C., Payne, T. E., Harrison, T. E., Harrison, J. J., Post, V. E., Shand, P., Love, A. J. & Wohling, D. L. 2018 Use of U-isotopes in exploring groundwater flow and inter-aquifer leakage in the south-western margin of the Great Artesian Basin and Arckaringa Basin, central Australia. *Applied Geochemistry* **98**, 331–344. doi.org/10.1016/j.apgeochem.2018.10.002.

Rana, B. K., Tripathi, R. M., Sahoo, S. K, Sethy, N. K., Srivastav, V. S., Shukla, A. K. & Puranik, V. D. 2010 Assessment of natural uranium and 226 Ra concentrations in groundwater around the uranium mine at Narwapahar, Jharkhand, India and its radiological significance. *Journal of Radioanalytical and Nuclear Chemistry* **285**(3), 711–717. doi.org/10.1007/s10967-010-0608-3.

Rao, N. S. 2006 Seasonal variation of groundwater quality in a part of Guntur district, Andhra Pradesh, India. *Environmental Geology* **49**(3), 413–429. doi:10.1007/s00254-005-0089-9.

Sahu, B. L., Banjare, G. R., Ramteke, S., Patel, K. S. & Matini, L. 2017 Fluoride contamination of groundwater and toxicities in Dongargaon Block, Chhattisgarh, India. *Exposure and Health* **9**(2), 143–146. doi.org/10.12403-016-022-3.

Sahu, P., Kisku, G. C., Singh, P. K., Kumar, V., Kumar, P. & Shukla, N. 2018 Multivariate statistical interpretation on seasonal variations of fluoride-contaminated groundwater quality of Lalganj Tehsil, Raebareli District (UP), India. *Environmental Earth Sciences* **77**(13), 1–11. doi.org/10.1007/s12665-018-7658-1.

Sahu, M., Sar, S. K., Dewangan, R. & Baghel, T. 2019 Health risk evaluation of uranium in groundwater of Bemetara district of Chhattisgarh state, India. *Environment, Development and Sustainability* **22** (8), 7619–7638. doi.org/10.1007/s10668-019-00539-6.
Sahu, M., Sar, S. K., Baghel, T. & Dewangan, R. 2020 Seasonal and geochemical variation of uranium and major ions in groundwater at Kanker district of Chhattisgarh, central India. *Groundwater for Sustainable Development* 10, 100330. doi.org/10.1016/j.gsd.2020.100330.

Saikia, R., Chetia, D. & Bhattacharyya, K. G. 2021 Estimation of uranium in groundwater and assessment of age-dependent radiation dose in Nalbari district of Assam, India. *SN Applied Sciences* 3 (1), 1–12. https://doi.org/10.1007/s42452-020-04071-5.

Sar, S. K., Sahu, M., Singh, S., Diwan, V., Jindal, M. & Arora, A. 2017 Assessment of uranium in groundwater from Durg District of Chhattisgarh state and its correlation with other quality parameters. *Journal of Radioanalytical and Nuclear Chemistry* 314 (3), 2339–2348. doi.org/10.1007/s10967-017-5587-1.

Sar, S. K., Diwan, V., Biswas, S., Singh, S., Sahu, M., Jindal, M. & Arora, A. 2018 Study of uranium level in groundwater of Balod district of Chhattisgarh state, India and assessment of health risk. *Human and Ecological Risk Assessment: An International Journal.* 24 (5), 691–698. doi.org/10.1080/10807039.2017.1397498.

Selvi, B. S., Vijayakumar, B., Rana, B. K. & Ravi, P. M. 2016 Distribution of natural uranium in groundwater around Kudankulam. *Radiation Protection and Environment* 39 (1), 25. doi.10.4103/0972-0464.185164.

Sharma, T., Sharma, A., Kaur, I., Mahajan, R. K., Litoria, P. K., Sahoo, S. K. & Bajwa, B. S. 2019 Uranium distribution in groundwater and assessment of age dependent radiation dose in Amritsar, Gurdaspur and Pathankot districts of Punjab, India. *Journal of Chemosphere* 607 – 616. https://doi.org/10.1016/j.

Singh, S., Rani, A., Mahajan, R. K. & Walia, T. P. S. 2003 Analysis of uranium and its correlation with some physico-chemical properties of drinking water samples from Amritsar, Punjab. *Journal of Environmental Monitoring* 5 (6), 917–921. https://doi.org/10.1039/B309493F.

Singh, M., Tapadia, K., Jhariya, D. & Sahu, P. 2021 Evaluation of uranium containing groundwater quality and non-carcinogenic risk assessment in inhabitant of Bijapur District of Chhattisgarh, Central India. *Journal of Radioanalytical and Nuclear Chemistry* 327 (2), 939–947. doi.org/10.1007/s10967-020-07572-0.

Smedley, P., Smith, B., Abesser, C. & Lapworth, D. 2006 *Uranium Occurrence and Behaviour in British Groundwater.* British Geological Survey Groundwater Systems & Water Quality Programme Commissioned Report CR/06/050. British Geological Survey, Keyworth, Nottingham.

Thorne, M. 2020 Assessment Modelling and the Evaluation of Radiological and Chemical impacts of uranium on humans and the environment. In: *Uranium in Plants and the Environment.* Springer, Berlin, pp. 193–216. doi.org/10.1007/978-3-030-14961-1_10.

USEPA (United States Environmental Protection Agency) 2011 *Edition of the Drinking Water Standards and Health Advisories EPA 820-R-11-002.* USEPA, DC.

WHO (World Health Organization) 2008 *Guidelines for Drinking Water Quality.* incorporating first addendum to third edition Recommendation Geneva 1:595.

WHO (World Health Organization) 2011 *Guidelines for Drinking-Water Quality,* 4th edn. World Health Organization, Geneva, Switzerland, 1–564.

Xiong, L., Alshamsi, D., Yi, P., Hou, X., Murad, A., Hussein, S., Aldahan, A. & Mohamed, M. M. 2020 Distribution of uranium isotopes in groundwater of the UAE: environmental radioactivity assessment. *Journal of Radioanalytical and Nuclear Chemistry.* doi.org/10.1007/s10967-020-07216-3.