Radiological And Chemotoxic Risk Assessments Caused By Uranium In Groundwater In Chandrapur District, Maharashtra, India

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Abstract:
The current study on groundwater contamination examines the chemical and radiological dangers associated with uranium contamination in groundwater. For the same 232 groundwater samples were analysed from 15 talukas in the Chandrapur district. The study also estimated pre-monsoon lifetime excess cancer risks (ECR) for mortality and morbidity in adults aged 70 years. The ECR was calculated using mathematical equations. The estimated ECR of death and disease for post-monsoon was between 4.19 E-045 and 1.002E-05 for mortality and between 1.010E-06 and 8.92E-05 for morbidity. All except one pre-monsoon sample satisfied ECR mortality and morbidity of AERB standards. The LADD and hazard quotient were also studied. The post-monsoon LADD concentration averaged 0.31592377 µg/kg/day and pre-monsoon average was 0.4386 µg/kg/day. Post-monsoons, chemical concentrations above the WHO criteria reduced from 9.48% to 8.62%. Post-monsoon adult HQ ranged from 0.001 to 7.71 µg/kg/day and pre-monsoon HQ levels averaged 0.511 µg/kg/day. Due to increased HQ levels, 11.2% of pre-monsoon samples were chemotoxic in nature.

Keywords: - Groundwater, Uranium, Risk Assessment, Annual Effective Dose, Cumulative Dose, Chandrapur

Abbreviations: AERB – Atomic Energy Regulatory Board
CGWB – Central Ground Water Board
ECR – Excess Cancer Risk
GSDA – Groundwater Survey and Development Agency
HQ – Hazard Quotient
LADD – Lifetime Average Daily Dose
USEPA – United State Environmental Protection Agency
WHO – World Health Organization

1. Introduction:

Groundwater is a common source of uranium since it is a naturally radioactive element (Duggal *et al*., 2021; Bhardwaj *et al*., 2020). Uranium dioxide or uranyl ions are formed when this long-lived radionuclide reacts with oxygen in the air (Amakom and Jibiri, 2010). Depending on the local geology and rock composition, groundwater may contain varying amounts of uranium. Groundwater uranium contamination is exacerbated by human activities such as burning coal, mining for metals, creating nuclear power, and using phosphate fertilizers (Kumar *et al*., 2016; Duggal *et al.,* 2017).

Humans are vulnerable to uranium's radiological (cancer-causing) and chemical (non-cancer-causing) toxicity (Zamora *et al*., 1998). Its radioactivity is less of a concern than its toxicity. Uranium is a nephrotoxic substance, meaning it causes harm to the kidneys, according to the World Health Organisation WHO (WHO, 2011). Premature hair greying, heart problems, and congenital abnormalities have all been linked to uranium exposure (USEPA, 2003). Humans' kidneys, bones, and liver can all be damaged by even trace amounts of uranium in drinking water (0.004 to 9.0 µg/L; Bajwa *et al.*, 2017; Kurttio *et al*., 2002; Zamora *et al*., 1998).

The United States Environmental Protection Agency (USEPA) has classed uranium as a Group A carcinogenic element due to its radioactive and chemical toxicity hazards (USEPA, 2012). The findings back up the notion that uranium should never be found in drinkable water. The US Environmental Protection Agency (EPA) and the World Health Organisation (WHO) have proposed a preliminary MCL of 30 µg/L in drinking water, although the AERB allows for up to 60 µg/L. Uranium is not included in the Bureau of Indian guidelines' drinking water guidelines.

Groundwater uranium levels have been the subject of several international and domestic investigations. Orloff and colleagues reported maximum uranium concentrations between 1.8 and 7780 µg/L in 2004. Groundwater in the Indian city of Kolar, Karnataka, has been discovered to have between 0.3 to 1442.9 µg/L of uranium (Babu *et al.*, 2008).
Assessing uranium in groundwater used for human consumption is crucial internationally and nationally. The current study was implemented with the objectives as

1) Firstly, the researchers wanted to determine how widespread uranium contamination was in drinking-water aquifers.
2) To evaluate cancer and non-cancer dangers to locals.

The groundwater in Jammu and Kashmir to Bangalore, Karnataka, but not the Chandrapur area, has been examined for uranium pollution. Chandrapur's groundwater is likely contaminated with uranium due to the city's lithology and geohydrology. Coal and other minerals may be found in abundance at Chandrapur. Since no prior research has been conducted in the area, this study sought to evaluate the chemical and radiological risks to residents from uranium in groundwater. The findings fill a critical information need and provide residents with the knowledge to lessen toxicological risks and safeguard their health.

1.1 Geography of the region

Please refer Fig. 1 for a location map of Chandrapur on Maharashtra's eastern border with the Vidarbha area. The district's location is between $19^0$30 and $20^0$45 north and $78^0$50 and $80^0$10 east longitudes. Its southern neighbour is Andhra Pradesh State; its western neighbour is Gadchiroli District; its eastern neighbour is Yavatmal District; and its northern neighbour is Gondia, Bhandara, Nagpur, and Wardha Districts (CGWB, 2011).

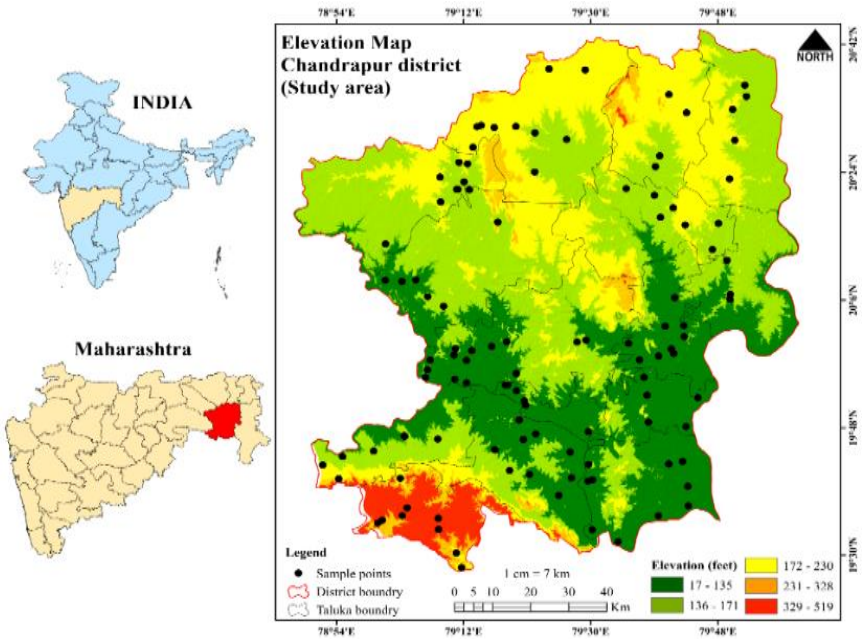

Fig: 1 Map showing the location of Chandrapur District in Maharashtra, its elevation, and sampling locations (source: Arc-GIS-10.8)

Chandrapur, a region in Maharashtra that spans an area of 11,364 km^2, is well-known for its mining reserves. As the Environmental Status Report (2007) notes, Chandrapur has earned the nickname "Black Gold City" due to the abundance of coal mines in the area.

Physiography and Geology

Situated between the Wardha and Wainganga basins, the Chandrapur district is physically split in two by the rivers that give it its name: the flat plains of the Wardha, Wainganga, and Penganga rivers, and the rocky upland region. Along the Wardha River, the plains are flat and expansive. The southern portion of the Wainganga River valley is characterized by undulating topography, while alluvial floodplains characterize the northern portion. The flat Penganga Valley may be found in the southwest part of the area. The entire district is included in the Godavari basin, and its principal rivers are the Wainganga, Wardha, and Penganga (Central Groundwater Board, 2009).

1.2 Hydrogeology of the District

The water-bearing formations in the Chandrapur district are composed of Deccan Trap Basalt, Vindhya Limestone, Alluvium, Lower Gondwana sandstone, and Archean metamorphic rocks (Fig. no. 2). Among these, the Kamthi sandstone, which is part of the Lower Gondwana group, forms the most promising aquifer (CGWB, 2009; Satapathy D. *et al*., 2009).

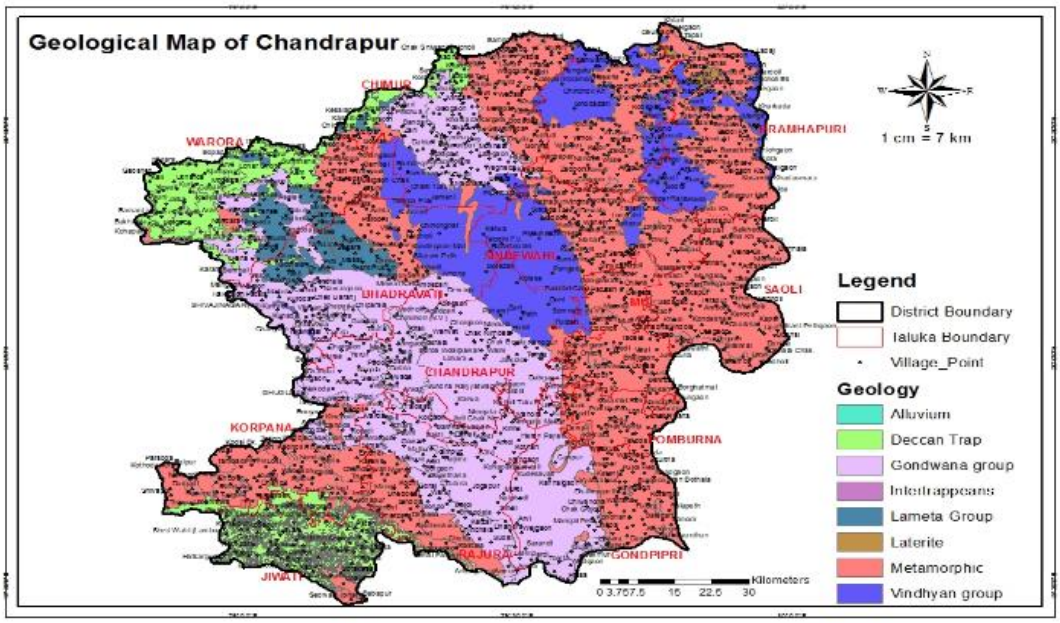

Fig:2. Geological Map of Chandrapur District (Source: GSDA, Chandrapur)

The area is part of the Gondwana supercontinent and the sedimentary basins. The Wardha Valley had Gondwana sedimentation, and the resulting Gondwana sediments now sit above the Valley's Archean rock formations. The area has a wide variety of stratigraphic strata, from Archean alluvium and laterites to those from more recent times (Satapathy *et al.*, 2009). The Archean rocks comprise quartzites, gneisses, and banded hematite quartzites. The Vindhyan group contains massive limestones and sandstones, which are fine-grained, calcareous, and white. The Deccan trap encompasses a small portion of the district, while the alluvium mainly consists of sand, silt, and clays found along the riverbanks. The map below illustrates the district's hydrogeological features.

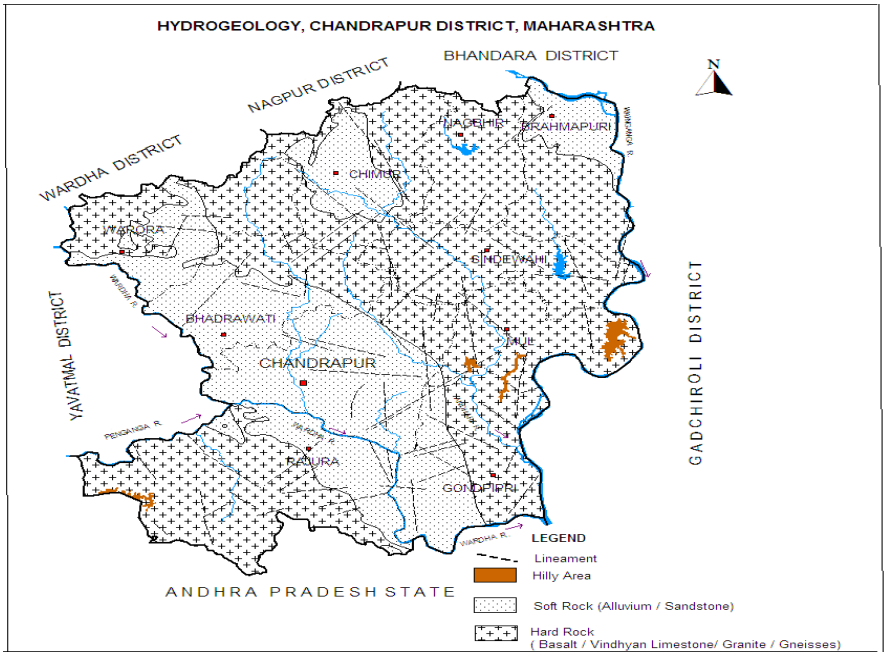

Fig: 3 Hydrogeological Map of Chandrapur District (Source: GSDA)

2. Literature Review:

While selecting the current topic, an extensive literature review was conducted at global, national, and local levels, guiding the researchers in this study. The literature review provided valuable insights and direction for the research work. In the table below, we summarise some relevant research on this issue. Orloff and colleagues (2004) estimated the maximum concentration to be between 1.8 and 7780 µg/L in the United States, whereas Brown and colleagues (1983) reported the lowest concentration to be between 0.5 and 1.0 µg/L in South Greenland. In 2008, Babu and co-investigator reported the highest uranium content in India to be in Kolar, Karnataka, with a range of 0.3-1442.9 µg/L, and Byju and colleagues reported the lowest concentration to be in South Coast district, Karnataka, with a range of 0.3-4.492 µg/L. According to the mentioned sources, the highest levels are far higher than those allowed by the WHO, USEPA, and AERB.

In Maharashtra, research on this topic has been conducted in Buldhana, Beed, and Aurangabad districts by Kale and co-investigators; however, no study has been found in the Chandrapur district of Maharashtra. The table below provides a brief overview of the literature review at international and national levels.

Table: 1 Worldwide Source of Groundwater Uranium

Sr. No.	Region	Uranium Concentration (µg/L)		References
		Range	Mean	
	International			
1	Argentina	0.04-11.0	-	Bomben *et al.*, 1996
2	Australia	0.05-160	2.1	Landstetter & Katzlberger., 2009
3	Bangladesh	<0.2-10	2.5	Frisbie *et al*., 2009
4	Ontario, Canada	0.05-4.21	-	OMEE., 1996
5	NE Portugal	8.2-3483	617.8	Costa *et al*., 2017
6	Switzerland	0.05-92.02	-	Stalder *et al.*, 2012
7	Kosovo	0.012-166	5	Berisha & Goessler., 2013
8	Canada	<1-845	-	Zamora *et al.*, 2009
9	Finland	0.02-6000	-	UNSCEAR., 2000
10	Ghana	<0.001-266	-	Rossiter *et al.*, 2010
11	Greece	0.015-1.4	-	UNSCEAR., 2008
12	Italy	0.02-5.2	-	UNSCEAR., 2000
13	Jordan	0.04-1400	-	Gedeon *et al.*,1994
14	Korea	0-3610	8	Shin *et al*., 2016
15	Kuwait	0.02-2.48	-	Bou-Rabee., 1995
16	Mongolia	<0.01-57	4.6	Nriagu *et al.*, 2012
17	Odeda area Nigeria	20.55-272.82	-	Amakom *et al*., 2010
18	Okchun belt Korea	0.5-263	-	Lee *et al*., 2001
19	San Joaquin Valley, California USA	0.04-2500	-	Jurgens *et al*., 2009
20	Saudi Arabia	<0.8-90.8	32.4	Shabana & Kinsara., 2014
21	South Greenland	0.5-1.0	-	Brown *et al.*, 1983
22	Sweden	<0.20-470	-	Selden *et al.*, 2009
23	Turkey	0.2-17.6	-	Kumru.,1995
24	USA	0.02-652	-	Cothern *et al.*, 1983
25	USA	1.8-7780	620	Orloff *et al*., 2004
	National			
1	Balod district, Chhattisgarh	0.56-78.93	-	Sar *et al*., 2017
2	Aurangabad, Maharashtra, India	0.012-16.673	0.068	Kale *et al*., 2018
3	Bangalore, Karnataka, India	0.2-770.1	-	Nagaiah *et al*., 2013
4	Beed district, Maharashtra, India	0.03-32.85	2.58	Kale *et al*., 2018
5	Bemetara district, Chhattisgarh, India	0.68-96.08	-	Sahu *et al*., 2019
6	Bhathinda, Punjab	9.72-186.6	-	Virk., 2016
7	Bhatinda, Punjab	11.7-113.7	-	Singh *et al*., 1995
8	Buldhana district, Maharashtra, India	0.10-13.06	2.48	Kale *et al*., 2021
9	Central Tamil Nadu	0.79-71.93	-	Adithya *et al*., 2017
10	Chamarajnagar, Karnataka, India	0.03-4.63	-	Nagaraju *et al*., 2014
11	**Chandrapur District, Maharashtra, India**	**0.001-417.74**	**-**	**Present Study**
12	Himachal Pradesh	0.56-10.11	2.17	Rani *et al*., 2013
13	Himachal Pradesh, Kulu, India	0.3-2.5	-	Singh *et al*., 2001
14	Himachal Pradesh, India	0.12-19.43	2.57	Kaur & Mehra., 2019
15	Eastern Uttar Pradesh	11-63.33	-	Kumar *et al*., 2015
16	Ganjam. Odisha, India	<0.2-13.6	4.3	Mohapatra *et al*., 2015
17	Garhwal Himalayan, Uttarakhand, India	0.02-36.7	7	Prasad *et al*., 2019
18	Gaya, Bihar	0.1-238.2	-	Kumar *et al*., 2020
19	Guwahati, Assam	0.08-5.32	-	Taukdar *et al*., 1983
20	Haryana, India	1.07-40.25	17.91	Panghal *et al*., 2017
21	Punjab	1.24-45.42	14.91	Rani *et al*., 2013
22	Hyderabad, Telangana	0.6-82	-	Balbudhe *et al*., 2011
23	Jaduguda uranium mining complex, India	0.5-28	-	Sethy *et al*., 2011
24	Hisar district, Haryana	1.2-274	32.5	Duggal *et al*., 2021
25	Jaduguda, Jharkhand, India	0.03-11.6	-	Patra *et al*., 2013
26	West Haryana, India	0.3-256.4	-	Balvinder Singh *et al*., 2014
27	Jammu & Kashmir, India	0.18-20.81	4.72	Kumar *et al*., 2016
28	Kolar, Karnataka	0.3-1442.9	-	Babu *et al*., 2008

29	Madurai, Tamil Nadu	0.2-156.84	-	Thivya *et al*., 2015
30	Nadia, West Bengal	0.21-20.9	-	Das *et al*., 2020
31	Mahendragarh district, Haryana	0.56-57.53	18.87	Mehra *et al*., 2017
32	Sirsa, Haryana	0.93-290	-	Duggal *et al*., 2017
33	Proposed uranium mining areas in Jharkhand	<0.5-24.5	-	Giri and Jha., 2012
34	Mumbai, Maharashtra, India	1.1-10.6	4.8	Sahu *et al*., 2014
35	Nalgonda, Andhra Pradesh, India	0.2-68	18.5	Brindha *et al*., 2012
36	South Coast district, Kerala, India	0.31-4.92	-	Byju *et al*., 2012
37	North Rajasthan, India	2.54-133	38.48	Rani *et al*., 2013
38	Patna, Bihar	0.1-14.5	-	Kumar *et al*., 2018
40	Peddagattu/Seripally, AP	0.6-521.15	-	Raghavendra *et al*., 2014
41	South Bihar, India	0.1-238.2	12.3	Kumar *et al*., 2018
42	Southwest Punjab, India	0.13-676	76.27	Saini *et al*., 2018
43	Southwest, Punjab	0.5-579	73.5	Bajwa *et al*., 2017
44	Southwest, Punjab	0.5-579	-	Bajwa *et al*., 2015
45	Tiruvannamalai, Tamil Nadu	0.2-25.8	5.4	Ganesh *et al*., 2020
46	Vishakhapatnam, AP	0.6-12.3	-	Bhangare *et al*., 2013
47	West Bengal India	<0.01-13.9	1.5	Rahman *et al*., 2015

3. Materials and Methods:

3.1 Grid Map of the Study Area

A grid map was created to facilitate the selection of sample locations, maximizing the information gathered. This map was used to track the accessibility of nearby highways and resources, ensuring accurate water sample collection. The current study employed a grid map that divided the sample region into 7×7 km sections across 15 talukas in the Chandrapur district (refer to the figure below).

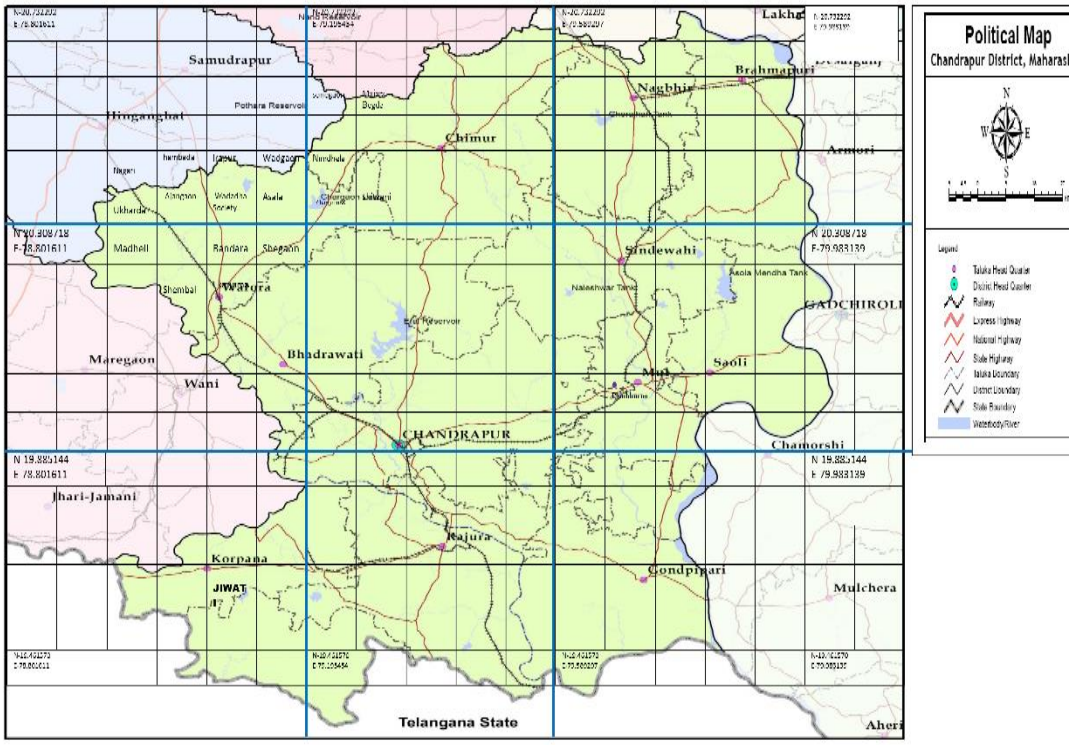

Fig:4 Grid Map of Chandrapur District of Maharashtra (Arc GIS-10.8)

3.2 Water Sampling and Analysis

Prior to and during the monsoons, 232 groundwater samples were collected in a 7x7 km grid pattern over 15 talukas in the Chandrapur district (see Figure 1). On-site measurements of pH, temperature, electrical conductivity, total dissolved solids, oxidation-reduction potential, and salinity were taken with a Bluetooth-enabled portable multiparameter kit (model no. HI98494). For the uranium assay, special, amber-coloured sample vials were used. The date and place of collection and other pertinent information were clearly labelled on each sample. The samples were rinsed in 10% HNO3 solution and then preserved until use. At the Civil Department of KITS in Ramtek, Maharashtra's Nagpur district, uranium concentration was determined using an LED-Fluorimeter (LF-2a).

3.3 Risk Assessment

Due to its ionising characteristics and chemical toxicity, uranium-contained drinking water poses both radiological and chemical toxicity problems. The primary routes of exposure to uranium in the human body are ingestion and inhalation. As a heavy metal, uranium exhibits carcinogenic traits. Its chemical toxicity can lead to nephrotoxicity, as documented by Kuttio P. *et al*. (2006) and Selden A.I. (2009).

3.4 Radiological Risk Assessment

The probability of acquiring cancer over the course of one's lifetime as a result of exposure to carcinogenic elements like uranium is known as radiological risk or Excess Cancer Risk (ECR) (Patra *et al*., 2013). The United States Environmental Protection Agency (USEPA) has created standard protocols for measuring ECR from naturally occurring uranium in drinking water, which are as follows:

U concentration in groundwater (Bq/L) ×Risk Factor (Bq/L) = Increased Cancer Risk. ------- 1

A conversion factor of 0.025 Bq/L is used to change the uranium content from micrograms per litre to becquerels per litre (Sahoo *et al.,* 2010).

The R-factor, or degree of danger, is determined by:

Exposure Probability (EF) = Risk Coefficient (per Bq) × IR (L/Day) TEP ---------- 2

The risk coefficient (r) for death from uranium exposure is 1.19 x 109, while the risk coefficient (r) for morbidity is 1.84 x 109 Bq/L (USEPA, 2000b; Mehra R. *et al.,* 2017). The Total Exposure Period (TEP) for adults is 70 years or 25,550 days (Rani et al., 2013; WHO, 2011; Duggal *et al*., 2017), and the Water Ingestion Rate (IR) is 1.38 L/Day (Kale A., and Kulkarni J., 2018).

3.5 Chemical Toxicity Risk Assessment

As a result of its chemical toxicity, uranium pollution in drinking water can affect human bones and kidneys (Kale A., 2021); exposure to uranium-contaminated water can cause chemical toxicity, which mainly affects the kidneys but can also cause other organ damage (Cantaluppi and Degetto, 2000). The Lifetime Average Daily Dose (LADD) measures chemical toxicity risk. LADD is measured using the following formula (WHO, 2011; Bhardwaj S. *et al*., 2020):

U * IR * EF * LE * BW * AT * LADD (µg/L/Kg/Day) ---------- 3

For adults, the average time of exposure is 25,550 days (Dang *et al.,* 1994), where U is the uranium content in the water sample (µg/L), IR is the ingestion rate (L/Day), EF is the exposure frequency, and BW is the body weight.

3.6 Hazard Quotient (HQ.)

When the HQ value is less than one (1), it is believed that drinking water containing uranium poses no threat to human health (AERB., 2004). To determine HQ, we use the formula:

$$HQ\ (g/L/Kg/Day) = \frac{LADD}{Rfd}$$

Where, Rfd is presumed as reference dose. According to many sources (including the World Health Organisation (1998), Duggal *et al*. (2016), and Ganesh *et al*. (2020), the Rfd is 4.53 µg/Kg/Day.

3.7 Assessment of Annual Effective Dose (AED)

By "annual effective dose," one might mean the biological dose. Human vulnerability to radiation is measured by its annual effective dose. As much as 87% of human radiation exposure worldwide occurs in India due to natural radiation sources (UNSCEAR., 2000). For an estimate of the radiation dose from consuming uranium, the formula AED = AC*F*I*365 can be used (International Atomic Energy Agency, 2016).

The formula is AC=average uranium concentration in litres, F=effective dose per unit intake in sieverts per year per litre, and I=age-adjusted daily water consumption in litres, where I=503.7 L (1.38365).

3.8 Cumulative Dose

Cumulative dose means the total dose resulting from exposure to ionizing radiation to a human being for a lifetime. The cumulative dose is calculated by using the following formula

Cumulative dose = DE (µSv) × lifetime (year)

DE means the annual effective dose and lifetime is 70 years (WHO, 2004)

4. Results and Discussion:

Table 2: Statistical data of parameters (Pre-Monsoon)

Statistical Parameters	U(ppb)	Average (Bq/l)	Mortality	Morbidity	LADD (µg/kg/day)	HQ. (µg/kg/day)	AED µSv/y	Cumulative Dose (Lifetime) µSv
Min	0.025	0.0006	2.51E-08	3.888E-08	0.000492857	0.000575096	0.0136	236.7176
Max	417.74	10.4435	4.38E-04	0.0006767	8.235445714	9.609621604	0.9519	16570.23
Average	22.251	0.5562655	2.33E-05	3.6046E-05	0.438678547	0.511876951	12.608	882.6015
Median	11.715	0.29285	1.23E-05	1.89767E-05	0.230952857	0.269489915	6.6378	465.8419

Table 3: Statistical data of parameters (Post Monsoon)

Statistical Parameters	U(ppb)	Average (Bq/l)	Mortality	Morbidity	LADD µg/kg/day	HQ (µg/kg/day)	AED µSv/y	Cumulative Dose (Lifetime) µSv
Min	0.0001	0.000002	1.002E-05	1.010E-06	0.001	0.001	0.01	0.03
Max	135.98	3.3995	4.19E-05	8.92E-05	2.68	0.052	77.05	5393.8
Average	16.0474871	0.401171224	1.37E-05	1.47E-05	0.31592377	0.00571661	9.02	631.08
Median	7.59	0.18975	7.34E-06	8.78E-06	0.1495	0.002	4.11	287.98

Table: 4 Permissible limits for radiological and chemical risk for groundwater uranium

Sr. No.	Parameter	Permissible Limit	Authority
1.	ECR	1.67×10^{-4}	AERB (2004)
2.	LADD	1 µg/kg/day	WHO (2011)
		4.53 µg/kg/day	AERB (2004)
3.	HQ	1 µg/L/Kg/Day	AERB (2004)
		1 µg/L/Kg/Day	WHO (2008)
4.	AED	100 µSv/y	WHO (2004)

Discussion:

4.1 Groundwater uranium concentration

Using 232 groundwater samples from the Chandrapur region, researchers determined the uranium concentrations and assessed the risks posed by radiological and chemical toxicity. The uranium concentrations in the water before the monsoons varied from 0.025 µg/L to 417.74 µg/L (Table 2). Bhisi village was found to have the lowest concentration. The presence of several cement mills and chemical facilities in the area may be to blame for the latter. After the monsoons finished, concentrations varied widely over the region, from as low as 0.001 µg/L in Wadodha to as high as 135.98 µg/L in the Manatekdi region (Table 3). According to Table 4, 12.93% and 18.10% of samples surpassed WHO allowed limits and 8.62 percent; and 7.75 percent and exceeded legal levels imposed by the Atomic Energy Regulatory Board (AERB), respectively, before and after the monsoon seasons.

Research by Amakom and Jibiri (2010) in South Western Nigeria and by Salden et al. (2009) in Sweden (Table 1) support the uranium concentration range of 0.025-417.74 µg/L before the monsoon (Table 2). Basal *et al.'s* (Table 1) research in Aligarh, UP, found a post-monsoon range of 0.001-135.98 µg/L. Rani et al. found similar findings for Rajasthan, where they used them to compare cancer risks posed by radiation with those posed by chemicals. In their research on water quality in South West Punjab, India, Bajwa et al. discovered that 67.87% of samples exceeded the WHO standard and 47.37% were above the AERB limit for uranium concentrations, respectively. The geomorphology and lithology of the area suggest localized uranium mineralization and dominant rock strata as possible causes of the region's elevated uranium levels. Lower than the quantities detected in our study before the monsoon but still beyond the WHO and AERB permissible limits were those found by Saikia et al. (2021) in the Nalbari area of Assam.

4.2 Excess Cancer Risk

The current study estimated that a 70-year-old adult's ECR for mortality and morbidity might be anywhere from 0.0006767 to 3.888E-08 µg/kg/day and 1.00210-5 to 4.1910-5 µg/kg/day before and after the monsoon, respectively, with a mean of 2.33E-05 and 1. The maximum daily intake of ECR allowed by the AERB is 1.67×10^{4} µg/kg (AERB, 2004). So, except for a single sample taken before the monsoon, all ECR values were shallow. Sahu and colleagues investigated uranium levels in the groundwater of the Bemetara area of Chhattisgarh, India, and found concentrations ranging from 1.15 to 83.5 µg/L before the monsoons and from 0.68 to 96.08 µg/L after that. The research took place in an area where limestone rocks are prevalent. Lifetime cancer risks were also computed in their study, with results falling in the range of 0.07106 to 5.06106 µg/kg/day before the monsoons and 0.04106 to 5.82106 µg/kg/day after that, all of which are below the World Health Organization's safe upper intake level. Amakom reported mortality rates of 1.91105 to 2.54104 µg/kg/day and morbidity rates of 2.93105 to 3.18104 µg/kg/day in his study of radiological and chemical risk the Indian state of Uttarakhand caused by exposure to uranium through potable groundwater. Since the groundwater's origin, depth, and geochemistry point to localized uranium mineralization and dominant rock strata, these results may be more accurate than ours. Saini and co-investigators estimated cancer risk at 3.64107 to 1.89103 µg/kg/day in South West Punjab and 3.08107 to 9.80106 µg/kg/day in North East Punjab. They also found that 35% of the analysed samples had uranium concentrations above the AERB-recommended maximum of 60 µg/L. These results surpass our own by indicating natural uranium mineralization due to suitable geological strata.

4.3 Lifetime Average Daily Dose (LADD) and HQ.

Our analysis of the chemical danger, as shown by the LADD computed using Equation 3, is presented in Tables 2 and 3. The daily doses range we saw was 0.0001-2.68 µg/kg, with an average of 0.3159. Consistent with our findings, Mehera et al. found a mean LADD value of 0.31 µg/kg/day when they studied groundwater uranium risk in the Mahendragarh district of Haryana. Amakom and Jibri observed higher LADD values in Nigeria (0.56-7.47 µg/kg/day), with the increased uranium content attributed to factors like source, depth, and geochemistry.

Pre-monsoon LADD levels published by Saikia *et al*. (2021) were 0.22-0.520 µg/kg/day, which is lower than our results but still within the WHO LADD limit of 1 µg/kg/day. Our study's higher levels might result from natural geology and human activity, such as mining. LADD levels before the monsoon varied from 0.04 to 3.15 µg/kg/day, whereas post-monsoon levels ranged from 0.03 to 3.63 µg/kg/day (Table 4), lending credence to our findings.

Between 0.07 and 5.25 µg/kg/day and 0.04 and 6.04 µg/kg/day, with mean values of 1.31 and 1.10, respectively, the hazard quotient (HQ) was assessed before and after the monsoons. These numbers are far higher than what is considered safe by the AERB (Table 4), posing a severe threat to human health from chemical toxicity. Researchers observed annual practical dose values below the WHO threshold of 0.096 to 69.34 µSv/y before and between 0.56 to 79.79 µSv/y after the monsoon, indicating that safe levels were maintained. Our findings were comparable and likewise well within the safe range.

LADD levels reported by Saikia *et al.* (2021) in the Nalbari area of Assam were lower than the WHO standard values, and our findings (0.022 to 0.520 µg/kg/day pre-monsoon and 0.044 to 0.755 µg/kg/day post-monsoon). Geology and human activity may both contribute to the higher values seen in our research area. Saikia also observed HQ levels below the WHO recommended limit, with levels between 0.005 to 0.115 µg/kg/day before the monsoon and between 0.011 and 0.167 µg/kg/day afterward (Table 4).

4.4 Annual Effective Dose (AED) and Cumulative Dose

Our study indicated that in the pre-monsoon season, the average annual effective dose (AED), which assesses a person's exposure to radiation, was 12.60859. This AED ranged from 0.0136 to 0.9519 µSv/y. On average, the total radiation exposure was 882.6015 µSv, with a range of 236.7176 µSv to 16570.23 µSv. During the dry season, the annual effective dose (AED) varied from 0.01 to 77.05 µSv (with an average of 9.02 µSv), while the lifetime effective dosage (LD) varied from 0.03% to 5,393.8 µSv (with an average of 631.08 µSv).

The AED found by Mehra *et al*. (2017) in the Mahendragarh district of Haryana was much lower than the maximum allowable dose of 100 µSv/y, with a range of 0.32-32.60 µSv/y and a mean value of 10.69 µSv/y. They also observed that the average cumulative dosage was 747.25 µSv, with a range of 22.29-2278.56 µSv. Kale and Kulkarni (2018) found lower values in the Aurangabad district, with an AED range of 0.00680-9.448 µSv/y and an average of 1.539 µSv/y. They found a mean cumulative dosage of 107.791 µSv, with a range of 0.47599–661.343 µSv.

According to Ganesh *et al*. (2020), the average annual effective dose (AED) at Tiruvannamalai, Tamil Nadu, India, was 0.069 µSv/y, with a range of 0.33-42.91 µSv/y. All samples' average effective dose (AED) was less than 100 µSv/y. The total radiation exposure varied from 21.19 to 2733 µSv, averaging 572.05 µSv. The existence of uranium-containing parent rock strata and the closeness of some study locations to mining sites likely contributed to more significant uranium contamination, which is why our readings were higher than theirs.

In the Hamirpur district of Himachal Pradesh, India, Bhardwaj *et al*. (2020) reported 120–270 µSv/y for the absorbed dose rate, with an average of 210 µSv/y. For the same reasons, these numbers were significantly higher than the global average of 70 µSv/y.

5. Conclusions:

1. This study assessed the radiological and chemotoxic health risks associated with groundwater uranium in pre and post-monsoon seasons. The evaluation included ECR for mortality and morbidity, LADD, HQ, AED, and cumulative dose for a 70-year-old.
2. All ECR values for mortality and morbidity in pre-monsoon and post-monsoon samples were below the permissible limit set by the AERB, except for one pre-monsoon sample.
3. Chemical toxicity risk (LADD) exceeded the WHO's permissible limit in 8.62% post-monsoon samples and 9.48% of pre-monsoon samples.
4. In 11.20% of pre-monsoon samples, HQ values were above the permissible limit, potentially causing adverse health effects due to chemotoxic risks for residents. Higher concentrations were observed in metamorphic and gneiss rocks, likely due to natural uranium mineralization in groundwater and human activities such as mining and industry.
5. The HQ values for 116 post-monsoon samples were below the permissible limit, suggesting that the water is safe from a chemical toxicity standpoint.
6. The annual effective dose (ADE) measures an individual's radiation exposure. In this study, ADE values for all samples were below the WHO's permissible limit of 100 µSv/y, indicating they are within safe limits.
7. Lower uranium levels in the study area could be attributed to uranium leaching from nearby aquifers in metamorphic and gneiss rock strata (Kale and Kulkarni, 2021).
8. It is recommended that residents avoid consuming water from sources with higher uranium concentrations. Raising awareness among the community can help prevent potential health issues.

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