Applied Water Science (2021) 11:83
https://doi.org/10.1007/s13201-021-01411-7

ORIGINAL ARTICLE

A peep into the state of ground water quality in the district of Tiruvannamalai, Tamil Nadu, India, from a radiological and chemical toxicity perspective

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Received: 18 April 2020 / Accepted: 12 April 2021 / Published online: 3 May 2021
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Abstract

Uranium concentration in the ground water samples from the district of Tiruvannamalai, Tamil Nadu, was measured using an LED fluorimeter. All the samples were qualified as potable water from the radiological perspective. Though some samples showed mild chemical toxicity, they are still safe for ingestion. Different risk coefficients were calculated, and they were compared with recommended safety limits specified by various agencies. Software tools such as QGIS 15, GraphPad Prism 8 and Surfer 15 were employed for developing maps and plots.

Keywords LED Fluorimeter · Lifetime cancer risk · Lifetime average daily dose · Whole body radiation dose · Cumulative whole body dose · Hazard quotient

Introduction

Water is an essential resource and a boon to the mankind. Due to rapid industrialisation and urbanisation, the quality of water is constantly deteriorating. The environmental changes have also made the availability of ground water very scarce in arid and semi-arid regions. Tiruvannamalai, a district in the north eastern part of Tamil Nadu, India, is relatively a dry region due to lack of surface water reservoirs and flowing rivers. Hence, the local population is largely dependent on ground water for cooking, drinking and agriculture. Due to a considerable drop in the ground water levels in the recent years, water obtained from ground water sources such as wells and borewells pose a higher risk of contamination due to rock water interaction. Contamination to some degree can also be attributed to extensive use of fertilizers by the peasant farmers in this district.

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Materials and methods

Study area: location, climate and geology

The study area for this research is the district of Tiruvannamalai spanning over an area of 6188 km^2 located at 11.55° and 13.15° north latitude and 78.20° and 79.50° east longitude (Fig. 1). The average population is 2,464,875 according to census 2011, with over 63% of the working population engaged in agriculture (DSH 2018). The average annual rainfall is reported to be only 813.1 mm (Report 2014) and is regularly prone to drought during summer. To make matters worse, there are no perennial rivers or water reservoirs available in the district forcing the public and farmers to rely on ground water either from bore wells or open wells.

The digital geospatial layers for the preparation of lithological map were obtained from the Geological Survey of India (GSI). Figure 2 shows the land cover of the district divided into square grids (10.85 km × 10.85 km)

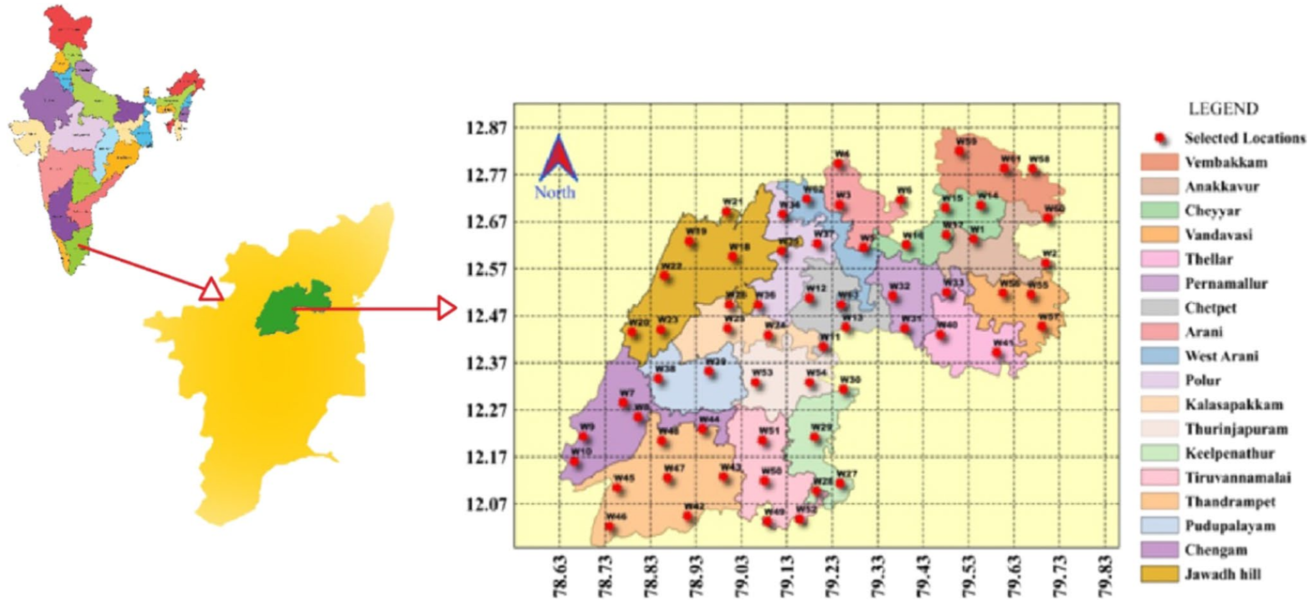


Fig. 1 Location of the study area—Tiruvannamalai District

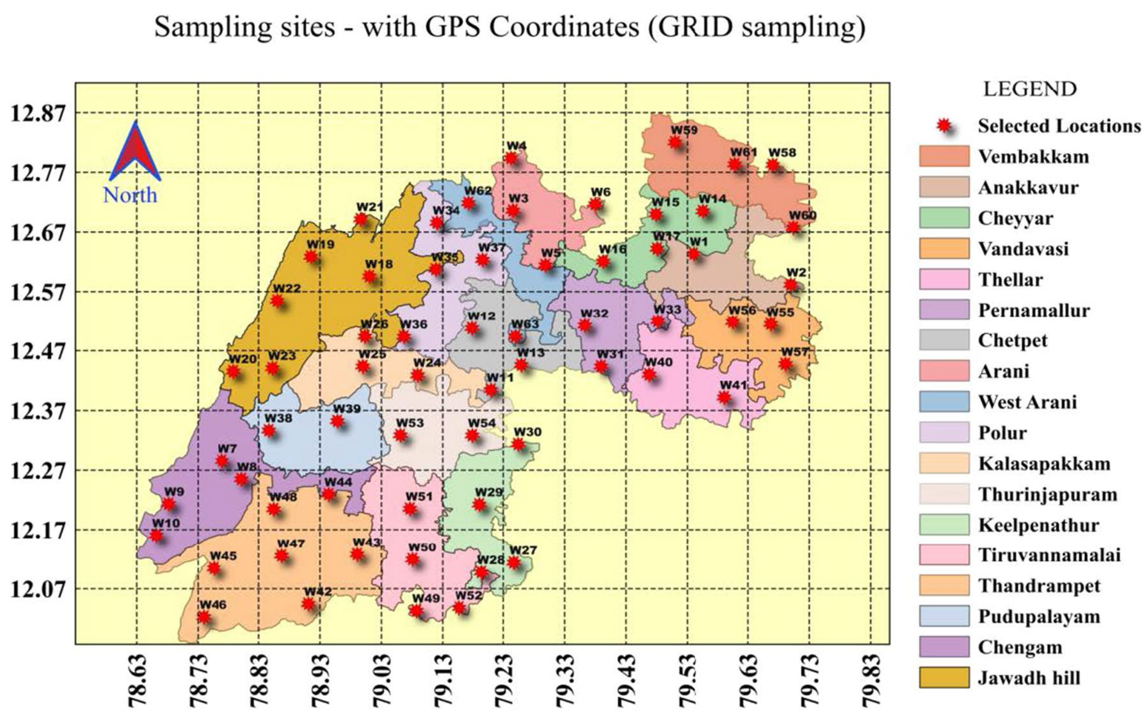


Fig. 2 Sampling sites with GPS coordinates within the grids

using QGIS—open-source mapping software. A location was identified in each grid depending on the availability and approachability of the sampling site. The geological study of this region indicates the presence of igneous and metamorphic rocks in general. The lithological map of the study area in Fig. 3 shows the presence of granites, charnockites, migmatite–Gneiss, Peninsular Gneiss, Sukinda ultramafics and alkaline complexes. Granites and

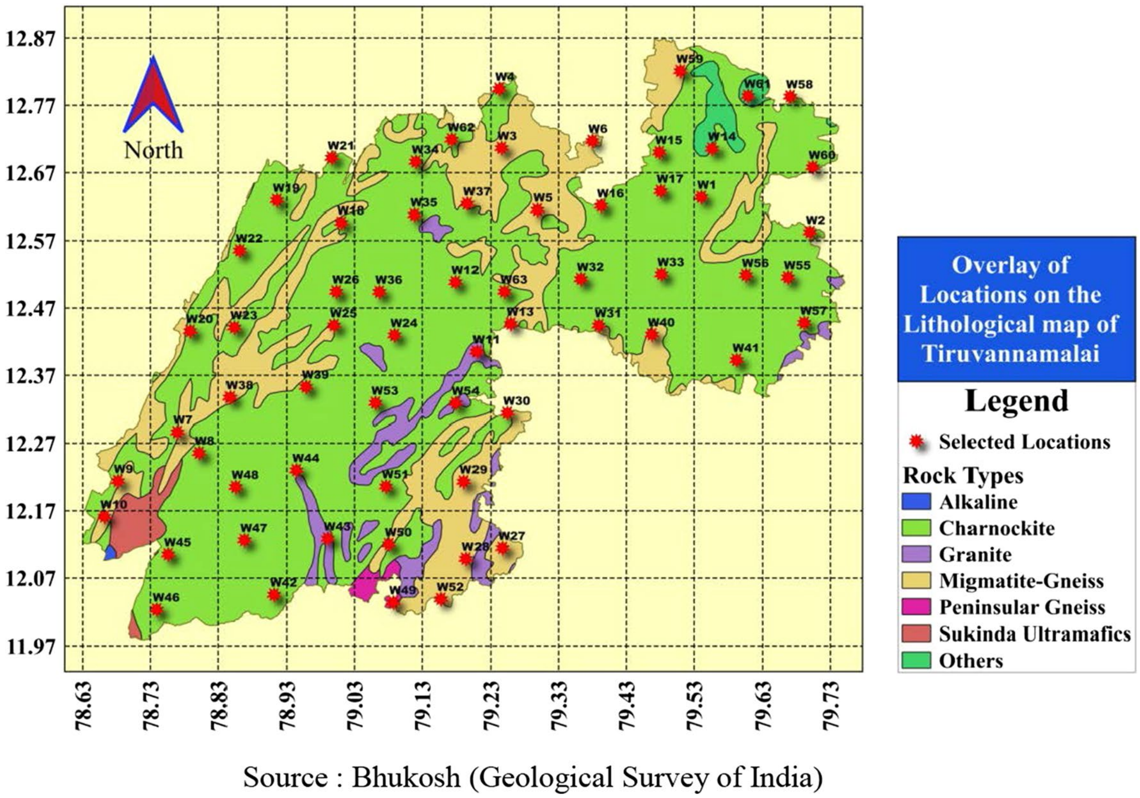


Fig. 3 Overlay of sampling locations on the lithology of the study area

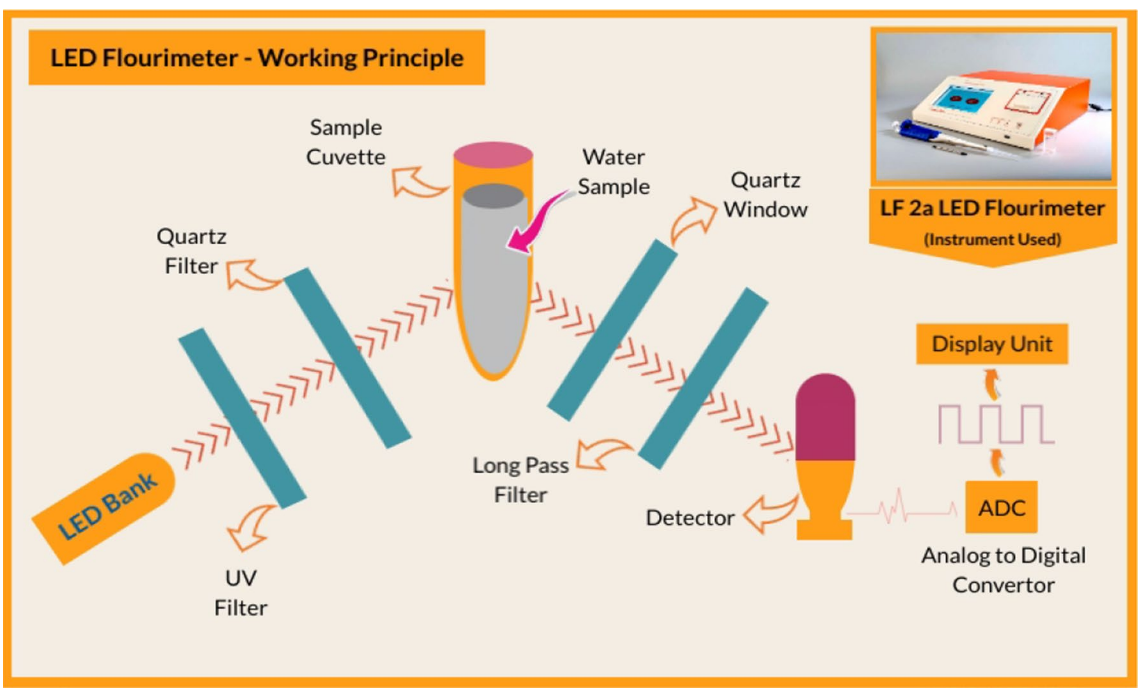


Fig. 4 LED fluorimeter working principle

Table 1 Age-dependent dose conversion factors and average daily water intake

Age group	Infant	1 year old	5 years old	10 years old		15 years old		Adult	
				M	F	M	F	M	F
DWI (l day^{-1}) (Sar et al. 2018)	0.8	1.3	1.7	2.4	2.1	3.3	2.3	3.7	2.7
DCF × 10^{-7} (µg kg^{-1}) (Virk 2016)	1.4	1.2	0.8	0.68	0.68	0.67	0.67	0.45	0.45

**M* male, *F* female, *DWI* daily water intake, *DCF* dose conversion factor

charnockites are well known for the presence of uranium in them, and this provides an ample reason to choose Tiruvannamalai District for this study. The water samples were carefully collected from each site using standard procedures prescribed by ICRP, and after completing the in situ measurements, they were transported to the laboratory for further analysis.

Sample collection

Sample collection containers were polyethylene bottles, each of 1 l capacity. The containers and their lids were washed using a dilute detergent solution and were rinsed thoroughly using 10% nitric acid solution (Virk 2016). The containers were then soaked overnight in a 1:1 diluted nitric acid solution and were further thoroughly dried before taking to them to the sample collection sites (Sar et al. 2018). In the case of a bore well, water was purged out from it for 5 minutes in order to obtain a fresh water sample. Each sample container was rinsed with the same water before it was filled with it. The temperature and GPS location of each sample were noted down in situ, and the container was then labelled neatly before it was transported to the laboratory.

Measurement of physico-chemical parameters

Using a multi-parameter tester designed by Hanna Instruments (HI98194), the TDS, pH and EC of the water sample were determined.

Measurement of uranium concentration

The samples were carefully filtered using a 0.45-µm filter paper and were subject to uranium analysis using an LED fluorimeter (Quantalase Uranium Analyser—QL/LEDF/01) developed by Laser Applications and Electronics Division at the Centre for Advanced Technology, Department of Atomic Energy, Indore, India (Bhangare et al 2013).

The LED fluorimeter causes fluorescence in a sample when it is set to match its excitation condition. A photomultiplier tube is used to detect fluorescence. An ADC converts the signal from the photomultiplier tube into digital pulses. The digital pulses are fed into a microcontroller and are later processed by the built-in computer software.

Each water sample is mixed with 10% of buffer solution (sodium pyrophosphate and orthophosphoric acid) to ensure a uniform yield for all complexes of uranium. 6 ml of the mixture is then poured carefully into quartz cuvette and placed in the LED fluorimeter. A schematic diagram in Fig. 4 shows the analytical procedure for uranium quantification using an LED fluorimeter.

Dose assessment

Chemical toxicity assessment

Lifetime average daily dose

The lifetime average daily dose (WHO 2011) refers to quantity of a substance that is ingested by a person per day per kg of his body weight.

$$\text{LADD}\left(\mu g\,\text{kg}^{-1}\,\text{Day}^{-1}\right) = \frac{C \times \text{DWI} \times \text{EF} \times \text{LE}}{\text{AT} \times \text{BW}} \tag{1}$$

where *C*—concentration of uranium (µg l^{-1}), DWI—daily water intake (3.7 l for an adult male and 2.7 l for an adult female) (USNAS 2004), EF—exposure frequency (365.25 days) (USEPA 2011), LE—life expectancy (70 years) (USEPA 2011), AT—average exposure time (365.25 × 70 = 25567.5 days) and BW—average body weight (70 kg) (USEPA 1991).

Hazard quotient

The extent to which ingestion of uranium from drinking water can be hazardous to an individual is determined by the hazard quotient (WHO 2011).

$$HQ = \frac{LADD}{RfD} \tag{2}$$

Table 2 Sampling locations and the calculated chemical toxicity parameters

Sample ID	Block	Sample location	Lat (north)	Long (east)	pH	EC mS cm^{-1}	TDS mg L^{-1}	U µg/l	LADD µg kg^{-1} day^{-1}		Hazard quotient			
											WHO RfD		AERB RfB	
									Male	Female	Male	Female	Male	Female
ANK—W1	Anakkavur	Anakkavur	12° 38′ 06.08″	79° 32′ 38.21″	8.24	28.5	771	3.152	0.17	0.12	0.3	0.2	0.1	0.1
ANK—W2		Vengodu	12° 35′ 00.50″	79° 42′ 10.59″	8.12	24.8	652	0.215	0.01	0.01	0.0	0.0	0.0	0.0
ARN—W3	Arani	Agarapalayam	12° 42′ 27.55″	79° 14′ 56.16″	7.88	48.4	1286	0.679	0.04	0.03	0.1	0.0	0.0	0.0
ARN—W4		Poosimalaikuppam	12° 46′ 44.40″	79° 14′ 44.14″	8.15	29.7	796	0.806	0.04	0.03	0.1	0.1	0.0	0.0
ARN—W5		Pudhupattu	12° 36′ 58.39″	79° 18′ 06.66″	8.09	18.9	505	0.492	0.03	0.02	0.0	0.0	0.0	0.0
ARN—W6		Randamkorrattar	12° 43′ 5.54″	79° 22′ 58.46″	8.02	27.3	730	0.65	0.03	0.03	0.1	0.0	0.0	0.0
CHN—W7	Chengam	Naradapattu	12° 12′ 54.58″	78° 41′ 06.25″	8.21	16.7	489	2.455	0.13	0.09	0.2	0.2	0.1	0.1
CHN—W8		Neepathurai	12° 09′ 44.33″	78° 38′ 54.47″	8.67	16.3	481	0.28	0.01	0.01	0.0	0.0	0.0	0.0
CHN—W9		Pakkiripalayam	12° 17′ 14.34″	78° 46′ 22.11″	8.24	18.5	503	0.23	0.01	0.01	0.0	0.0	0.0	0.0
CHN—W10		Pinjur	12° 15′ 24.41″	78° 48′ 18.19″	8.39	17.8	491	0.635	0.03	0.02	0.1	0.0	0.0	0.0
CHT—W11	Chetpet	Mansurabath	12° 24′ 22.63″	79° 12′ 47.32″	8.19	28.8	799	1.698	0.09	0.07	0.1	0.1	0.1	0.1
CHT—W12		Pulivanandal	12° 30′ 34.38″	79° 10′ 55.91″	8	76.7	2036	43.258	2.29	1.67	3.8	2.8	1.9	1.4
CHT—W13		Seyanandal	12° 27′ 51.21″	79° 15′ 44.90″	8.12	11.4	270	0.9	0.05	0.03	0.1	0.1	0.0	0.0
CHY—W14	Cheyyar	Devanathur	12° 37′ 20.69″	79° 23′ 45.15″	8.25	48.5	1325	3.631	0.19	0.14	0.3	0.2	0.2	0.1
CHY—W15		Murugathanpoondi	12° 42′ 04.94″	79° 28′ 54.94″	8.02	10.4	233	0.17	0.01	0.01	0.0	0.0	0.0	0.0
CHY—W16		Nadumbarai	12° 42′ 24.21″	79° 33′ 35.34″	8.24	21.5	572	1.671	0.09	0.06	0.1	0.1	0.1	0.1
CHY—W17		Parasur	12° 38′ 38.17″	79° 29′ 02.15″	7.85	27.8	727	1.635	0.09	0.06	0.1	0.1	0.1	0.1
JHL—W18	Jawadh Hills	Kilayur	12° 27′ 12.75″	78° 46′ 30.53″	8.02	19.6	511	4.393	0.23	0.17	0.4	0.3	0.2	0.1
JHL—W19		Nammiyambattu	12° 40′ 35.59″	78° 59′ 18.00″	8.15	23.1	569	1.198	0.06	0.05	0.1	0.1	0.1	0.0
JHL—W20		Palamarthur	12° 33′ 23.55″	78° 51′ 49.09″	8.29	15.5	440	0.989	0.05	0.04	0.1	0.1	0.0	0.0
JHL—W21		Seangadi	12° 34′ 50.91″	79° 01′ 49.07″	8.21	36.9	925	5.774	0.31	0.22	0.5	0.4	0.3	0.2
JHL—W22		Veerappanur	12° 37′ 49.55″	78° 55′ 06.46″	7.85	42.1	1102	9.204	0.49	0.36	0.8	0.6	0.4	0.3
JHL—W23		Kidampalayam	12° 29′ 43.40″	79° 00′ 22.51″	8.04	32.8	860	0.435	0.02	0.02	0.0	0.0	0.0	0.0
KAL—W24	Kalsapakkam	Parvathimalai	12° 26′ 42.89″	79° 00′ 10.33″	7.76	18.8	581	1.223	0.06	0.05	0.1	0.1	0.1	0.0
KAL—W25		Parvathimalai RF	12° 25′ 14.23″	78° 54′ 55.38″	8.1	11.1	285	0.522	0.03	0.02	0.0	0.0	0.0	0.0
KAL—W26		Pillur	12° 25′ 50.55″	79° 05′ 31.78″	8.15	23.7	637	2.52	0.13	0.10	0.2	0.2	0.1	0.1
KIL—W27	Kilpenathur	Angunam	12° 05′ 58.21″	79° 10′ 50.79″	8.35	17.1	512	1.53	0.08	0.06	0.1	0.1	0.1	0.0
KIL—W28		Panniyur	12° 06′ 56.14″	79° 15′ 00.80″	6.75	13.4	408	0.39	0.02	0.02	0.0	0.0	0.0	0.0
KIL—W29		Sevarapundi	12° 18′ 55.10″	79° 15′ 26.54″	8.24	33.9	922	4.642	0.25	0.18	0.4	0.3	0.2	0.1
KIL—W30		Vedanatham	12° 12′ 51.31″	79° 11′ 39.18″	7.28	29.2	767	4.054	0.21	0.16	0.4	0.3	0.2	0.1
PER—W31	Pernamallur	Melnanthiyambadi	12° 26′ 42.64″	79° 23′ 32.77″	8.2	10.8	341	0.346	0.02	0.01	0.0	0.0	0.0	0.0
PER—W32		Melpoondi	12° 30′ 50.70″	79° 21′ 57.89″	7.79	33.4	652	1.296	0.07	0.05	0.1	0.1	0.1	0.0
PER—W33		Vallam	12° 31′ 16.88″	79° 29′ 05.69″	8.15	16.3	391	0.277	0.01	0.01	0.0	0.0	0.0	0.0

Table 2 (continued)

Sample ID	Block	Sample location	Lat (north)	Long (east)	pH	EC mS cm^{-1}	TDS mg L^{-1}	U µg/l	LADD µg kg^{-1} day^{-1}		Hazard quotient			
											WHO RfD		AERB RfB	
									Male	Female	Male	Female	Male	Female
PUD—W34	Pudupalayam	Kanji	12° 21′ 14.60″	78° 57′ 41.36″	8.13	15.7	412	1.169	0.06	0.05	0.1	0.1	0.1	0.0
PUD—W35		Monnormangalam	12° 20′ 39.79″	78° 51′ 13.91″	8.24	22.2	505	0.552	0.03	0.02	0.0	0.0	0.0	0.0
POL—W36	Polur	Ananthapuram	12° 41′ 14.54″	79° 07′ 25.22″	8.01	71.6	1914	8.656	0.46	0.33	0.8	0.6	0.4	0.3
POL—W37		Edaipirai	12° 29′ 42.32″	79° 04′ 11.39″	7.84	84.2	2194	16.907	0.89	0.65	1.5	1.1	0.7	0.5
POL—W38		Illupakkam	12° 37′ 30.87″	79° 11′ 58.18″	8.2	14.2	388	0.47	0.02	0.02	0.0	0.0	0.0	0.0
POL—W39		Thurinjikuppam	12° 36′ 32.79″	79° 07′ 17.97″	8.06	10.8	292	0.336	0.02	0.01	0.0	0.0	0.0	0.0
TEL—W40	Thellar	Seeyamangalam	12° 25′ 54.09″	79° 28′ 15.03″	8.2	18.8	522	1.069	0.06	0.04	0.1	0.1	0.0	0.0
TEL—W41		Theyyar	12° 23′ 37.51″	79° 35′ 40.43″	8.16	31.8	845	0.502	0.03	0.02	0.0	0.0	0.0	0.0
THD—W42	Thandrampet	Beemarapati	12° 02′ 27.18″	78° 44′ 32.70″	8.3	25.6	683	0.197	0.01	0.01	0.0	0.0	0.0	0.0
THD—W43		Kuvilam	12° 02′ 46.38″	78° 54′ 51.39″	8.11	21.6	640	2.09	0.11	0.08	0.2	0.1	0.1	0.1
THD—W44		Malamanjanur	12° 07′ 38.58″	78° 52′ 13.71″	8.39	22.2	623	1.26	0.07	0.05	0.1	0.1	0.1	0.0
THD—W45		Melpasar	12° 06′ 22.15″	78° 44′ 33.54″	8.17	9.7	259	2.52	0.13	0.10	0.2	0.2	0.1	0.1
THD—W46		Nedungavadi	12° 13′ 52.46″	78° 56′ 50.23″	8.09	13.6	357	0.802	0.04	0.03	0.1	0.1	0.0	0.0
THD—W47		Sathanoor	12° 12′ 22.88″	78° 51′ 27.46″	7.95	9.5	255	1.071	0.06	0.04	0.1	0.1	0.0	0.0
THD—W48		Vakkilapattu	12° 07′ 46.85″	78° 59′ 37.26″	8.16	27.9	752	3.695	0.20	0.14	0.3	0.2	0.2	0.1
TIR—W49	Tiruvannamalai	Devanur	12° 02′ 05.48″	79° 05′ 25.13″	8.45	30.2	827	2.067	0.11	0.08	0.2	0.1	0.1	0.1
TIR—W50		Kattompoondi	12° 07′ 16.08″	79° 05′ 02.03″	7.82	34.2	882	0.624	0.03	0.02	0.1	0.0	0.0	0.0
TIR—W51		Melathikam	12° 12′ 25.79″	79° 04′ 46.54″	8.1	22	603	1.345	0.07	0.05	0.1	0.1	0.1	0.0
TIR—W52		Virthuvilanginan	12° 02′ 23.12″	79° 09′ 38.20″	7.89	47.2	311	3.003	0.16	0.12	0.3	0.2	0.1	0.1
TUR—W53	Turinjapuram	Karunthuvambadi	12° 19′ 49.27″	79° 03′ 50.62″	7.95	29.9	809	3.261	0.17	0.13	0.3	0.2	0.1	0.1
TUR—W54		Mangalam	12° 19′ 48.33″	79° 10′ 57.77″	8.12	47.5	1247	3.565	0.19	0.14	0.3	0.2	0.2	0.1
VAN—W55	Vandavasi	Badhur	12° 26′ 56.57″	79° 41′ 39.92″	8.29	8.46	855	0.243	0.01	0.01	0.0	0.0	0.0	0.0
VAN—W56		Vazhur	12° 30′ 59.93″	79° 40′ 13.52″	8.22	36.2	1012	0.331	0.02	0.01	0.0	0.0	0.0	0.0
VAN—W57		Vengunam	12° 31′ 12.10″	79° 36′ 30.36″	8.04	36	958	2.072	0.11	0.08	0.2	0.1	0.1	0.1
VEM—W58	Vembakkam	Abdullapuram	12° 47′ 03.42″	79° 40′ 25.24″	8.53	1.275	730	0.645	0.03	0.02	0.1	0.0	0.0	0.0
VEM—W59		Randam	12° 47′ 15.45″	79° 28′ 13.28″	8.4	33.2	869	2.601	0.14	0.10	0.2	0.2	0.1	0.1
VEM—W60		Sodiambakkam	12° 43′ 39.32″	79° 41′ 22.92″	7.96	96.4	2488	15.231	0.81	0.59	1.3	1.0	0.7	0.5
VEM—W61		Vembakkam	12° 47′ 12.71″	79° 35′ 27.77″	8.07	84.2	2115	14.548	0.77	0.56	1.3	0.9	0.6	0.5
WAR—W62	West Arani	Devikapuram	12° 29′ 43.73″	79° 15′ 11.49″	8.29	39.7	981	2.365	0.13	0.09	0.2	0.2	0.1	0.1
WAR—W63		Ramasanikuppam	12° 43′ 13.15″	79° 10′ 35.56″	7.94	73.8	1872	8.372	0.44	0.32	0.7	0.5	0.4	0.3

Table 3 pH—comparison with BIS (10,500:2012) and WHO (2011) limits

	BIS (2012)	WHO (2011)	No of samples
Within the acceptable limit	6.5–8.5	6.5–8.5	61
Below the acceptable limit	< 6.5	< 6.5	0
Above the acceptable limit	> 8.5	> 8.5	2

where LADD—lifetime average daily dose and RfD—reference dose (0.6 µg/kg and 1.2 µg/kg are the reference doses prescribed by WHO (2011) and AERB 2004, respectively).

Radiological risk analysis

Whole body radiation dose

Annual whole body radiation dose (WHO 2011) is given by Equation 3

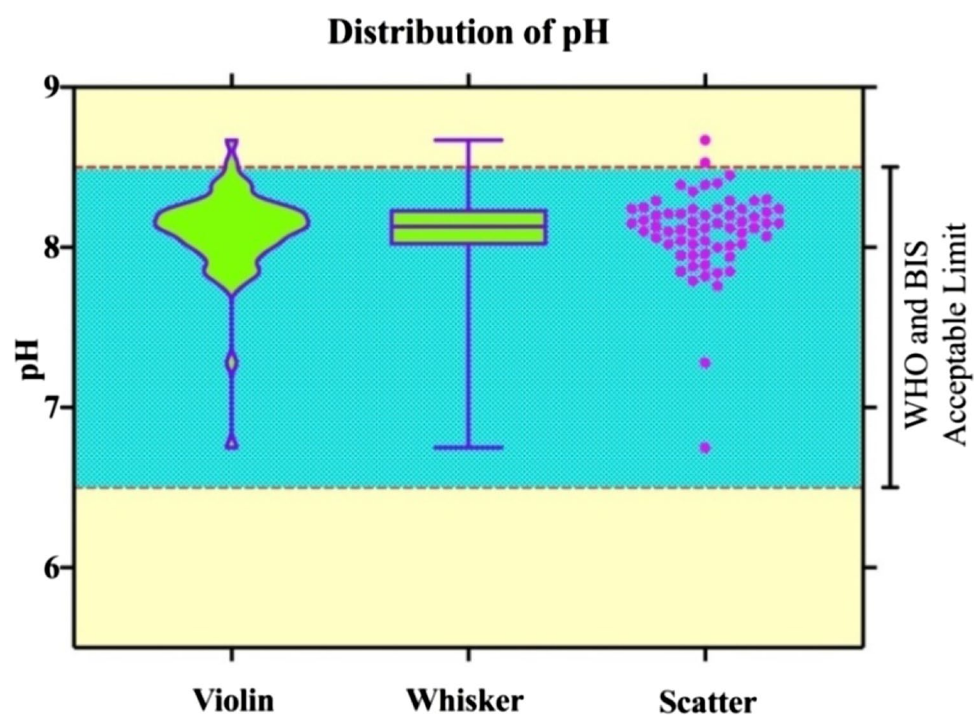


Fig. 5 Distribution of pH in the samples

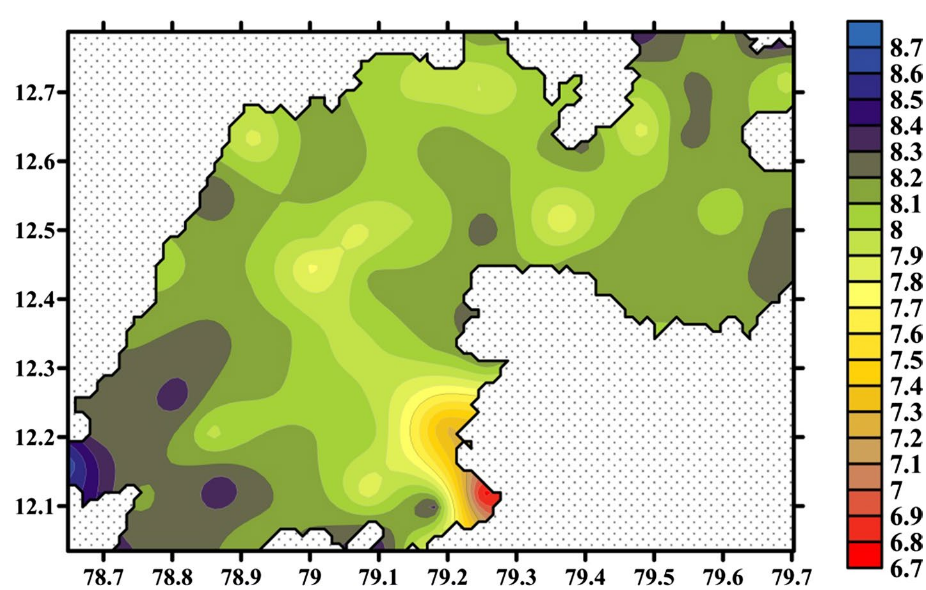


Fig. 6 Spatial distribution of pH in the study area

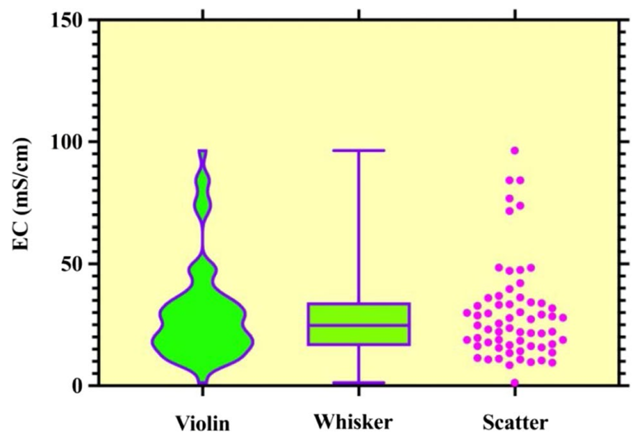


Fig. 7 Distribution of EC in the samples

$$D\left(\mu\text{SvYear}^{-1}\right) = \text{Ac} \times \text{DWI} \times \text{EF} \times \text{DCF} \quad (3)$$

where Ac—activity concentration of uranium (Bq/l), DWI—daily water intake (L), EF—exposure frequency (365.25 days) (USEPA 2011) and DCF—dose conversion factor (Sv/Bq). Table 1 shows the age-dependent conversion factors prescribed by ICRP (1995) (ref).

Cumulative whole body dose

Cumulative whole body radiation dose (WHO 2011) is the whole body radiation dose over the life span of an individual.

$$CD\,(\mu\text{Sv}) = D\left(\mu\text{SvYear}^{-1}\right) \times \text{LE} \quad (4)$$

where LE is the average life expectancy (70 years) (USEPA 2011).

Lifetime cancer risk

Lifetime cancer risk due to the ingestion of uranium contaminated water is given by Equation 5 (USEPA 2011)

$$\text{LCR} = \text{Ac} \times R \quad (5)$$

where Ac—activity concentration of uranium (Bq/l) and R—risk factor.

Risk factor R is calculated using Equation 6

$$R = \text{RC} \times \text{DWI} \quad (6)$$

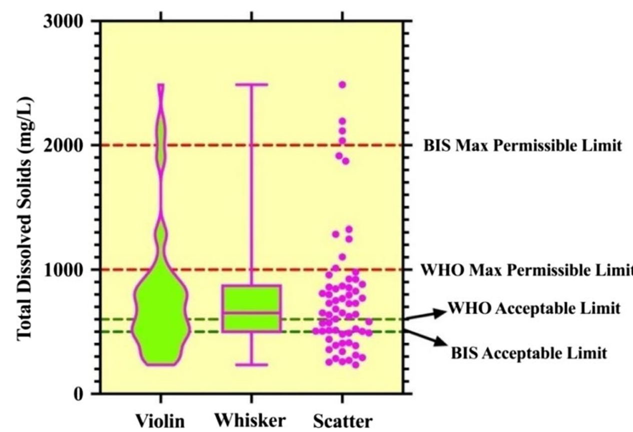
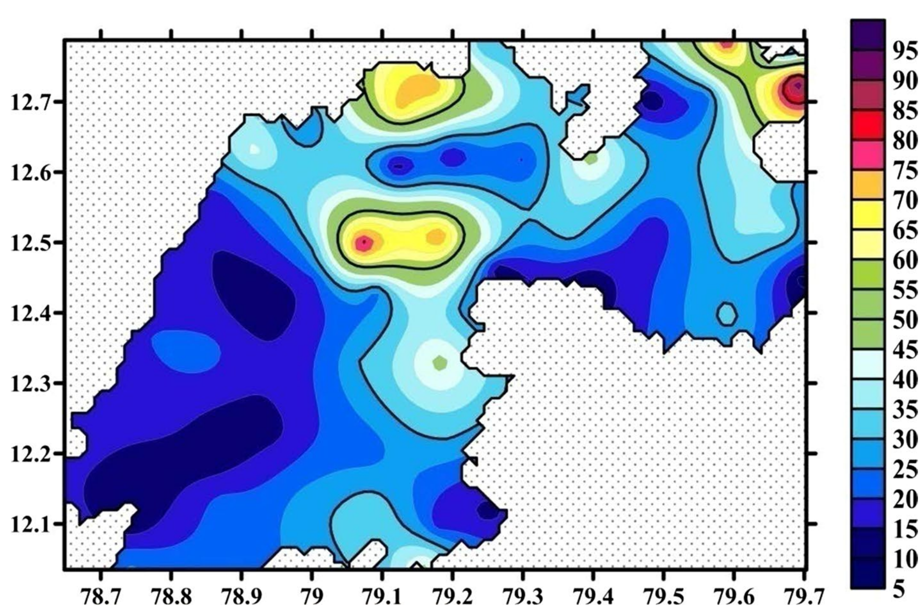


Fig. 9 Distribution of TDS in the samples

Fig. 8 Spatial distribution of EC in the study area



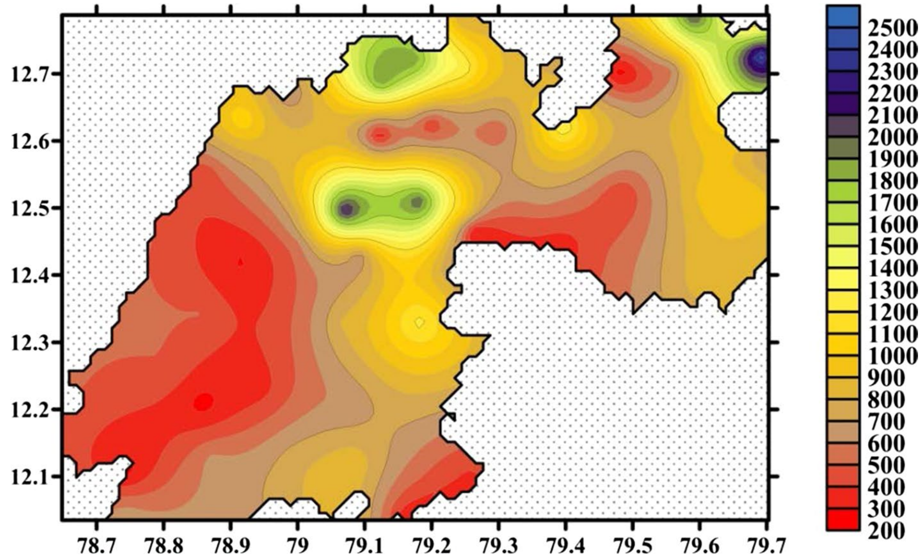


Fig. 10 Spatial variation of TDS in the study area

Table 4 TDS—comparison with BIS 2012 and WHO (2011) limits of safety

	BIS (2012)		WHO (2011)	
	Limit (mg/l)	No of samples	Limit (mg/l)	No of samples
Within the acceptable limit	< 500	17	< 600	28
Below the maximum permissible limit	> 500	42	> 600	28
Above the maximum permissible limit	> 2000	4	> 1000	11

Table 5 Samples qualifying and disqualifying the permissible limits

	WHO (2011)	USEPA (2011)	UNSCEAR (1982)	ICRP (1995)	AERB (2004)
Permissible limit (µg/l)	15	30	9	1.9	60
No of samples within the permissible limit	60	62	58	38	63
No of samples exceeding the permissible limit	3	1	5	25	0

where RC—risk coefficient (mortality and morbidity) (USEPA 2011) and DWI—daily water intake.

Results and discussion

A total of 63 ground water samples were collected from the district of Tiruvannamalai, Tamil Nadu. Basic physico-chemical parameters such as pH, EC and TDS for all the samples were determined using a multi-parameter tester. Table 2 shows all the 63 samples with their corresponding parameters and their GPS coordinates.

pH

pH is the measure of the concentration of hydrogen ions in a given sample. It measures the relative presence of hydrogen and hydroxyl ions on a 14-point scale ranging from 0 to 14. The pH value is represented in logarithmic units, i.e., an increase or decrease in pH by 1 unit would mean a tenfold increase or decrease in the sample's acidity. The pH of the samples ranged from 6.75 to 8.67 with a mean value of 8.1. Only samples from locations CHN-W8 (Neepathurai) (8.67) and VEM-W58 (Abdullapuram) (8.53) were found to marginally fall out of the safety range specified in both the WHO (2011) and BIS (2012) guidelines indicating slight alkalinity. Table 3 shows the number of samples qualifying the safety

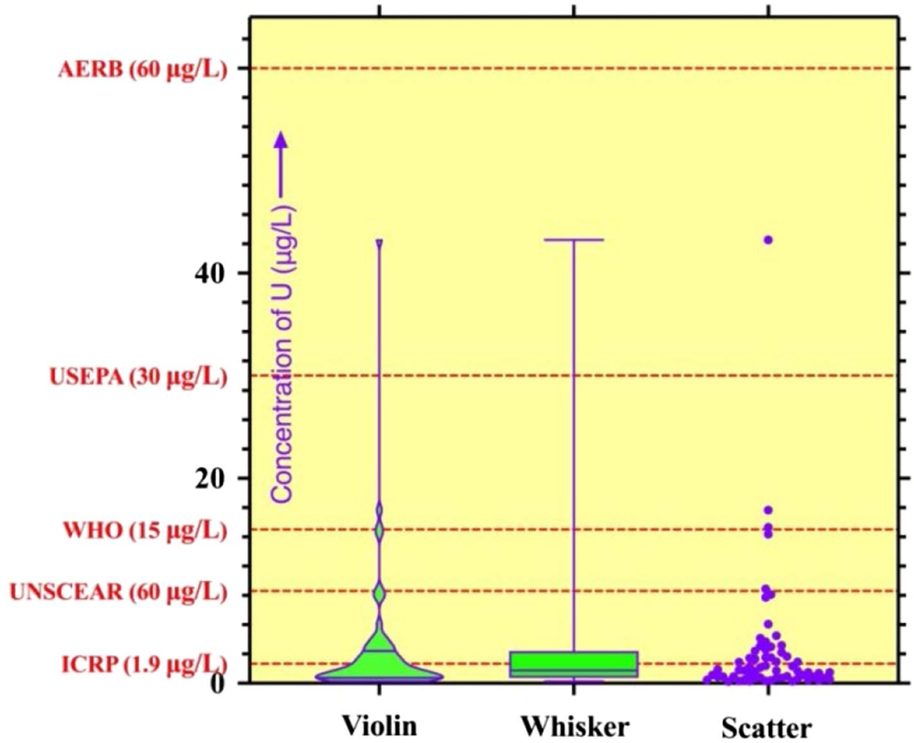


Fig. 11 Distribution of uranium concentration in the samples

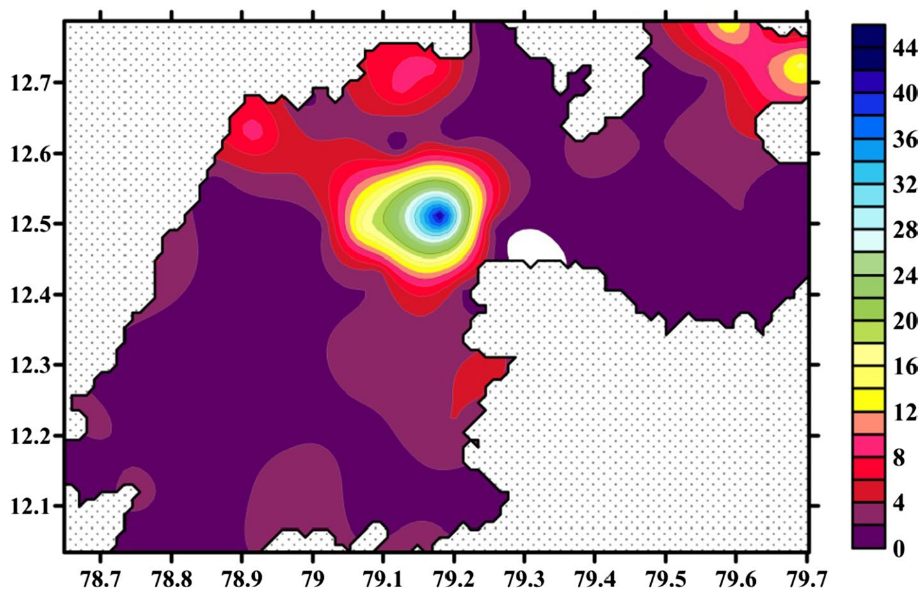


Fig. 12 Spatial distribution of uranium concentration in the study area

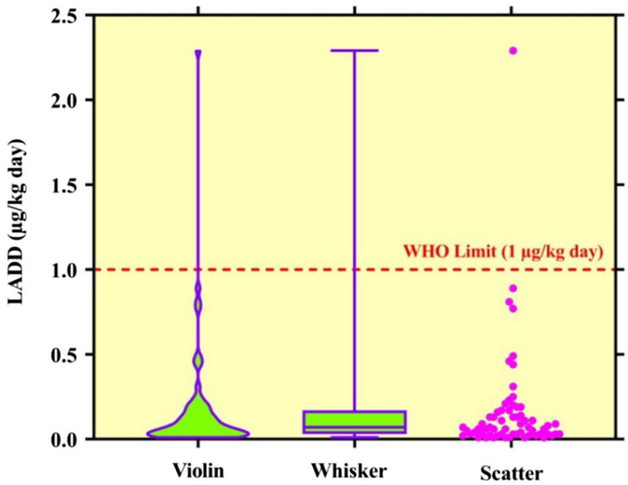


Fig. 13 Frequency distribution of LADD in adult males

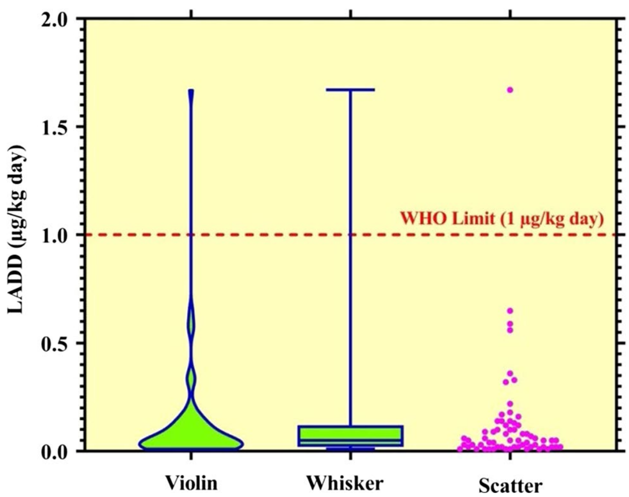


Fig. 14 Frequency distribution of LADD in adult females

limits of BIS and WHO. Figure 5 shows the distribution of pH in the samples, and Figure 6 shows the spatial distribution in the study area.

EC

Electrical conductivity known as specific conductance is the ability of the sample to allow the passage of electric current through it. Ground water shows higher electrical conductivity due to the presence of dissolved salts due to rock water interaction. Hence, electrical conductivity of ground water in a region will depend largely on its geology with which it interacts. EC of the ground water samples ranged between 1.275 and 96.4 mS cm^{-1} with the mean value of 29.67 mS cm^{-1}. All the water samples fall within the acceptable BIS limits (BIS 2012). Distribution of EC in the samples and the spatial variation of EC in the study area are shown in Figs. 7 and 8, respectively.

TDS

Water being a good solvent allows the easy dissolution of many inorganic salts and also some organic substances. The TDS measurements of the samples ranged from 233 to 2488 mg/l with a mean value of 790 mg/l. On comparison with the WHO (2011) set water safety guidelines 26 samples were found to be within the acceptable limit of 600 mg/l and 26 samples exceeded it, whereas 11 samples were unpalatable as they exceeded the maximum permissible limit of 1000 mg/l. Considering the BIS (BIS 2012) guidelines 17 samples fell within the acceptable limit (<500 mg/l) and 42 samples exceeded it, whereas 4 samples from Pulivanandal (CHT-W12), Edaipirai (POL-W37), Sodiambakkam (VEM—W60) and Vembakkam (VEM W-61) exceeded the maximum permissible limit of 2000 mg/l. Distribution of TDS in the samples and the spatial variation of TDS in the study area are shown in Figs. 9 and 10, respectively. Table 4 shows the number of samples within and out of the range specified by BIS and WHO.

Concentration of uranium

The concentration of uranium in the samples was determined using an LED fluorimeter. The minimum concentration was recorded to be 0.17 µg/l and the maximum as 43.26 µg/l. The mean concentration was found to be 3.22 µg/l. The permissible limits of uranium concentration in water have been recommended by various agencies such as the WHO (2011), USEPA (2011), ICRP (1995), UNSCEAR (1982) and AERB (2004). In comparison with the WHO set permissible limit of 15 µg l^{-1}, it was observed that 3 samples from Pulivanandal (CHT-W12), Edaipirai (POL-W37) and Sodiambakam (VEM-W60) exceeded the limit. UNSCEAR (UNSCEAR 1982) has set a limit of 9 µg/l which has been exceeded by 5 samples from Pulivanandal (CHT—W12), Veerapanur (JHL—W22),

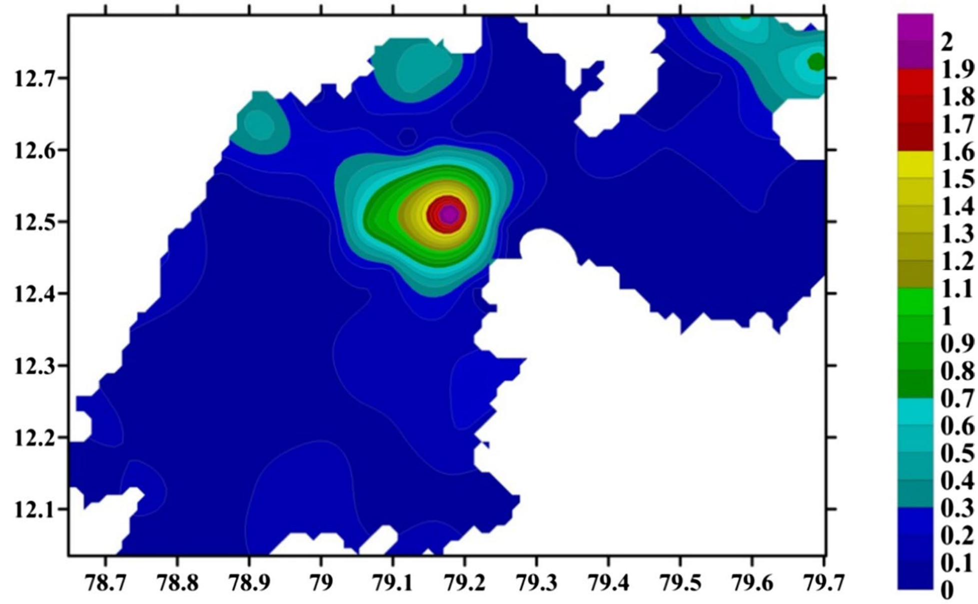


Fig. 15 Spatial distribution of LADD in the study area for adult males

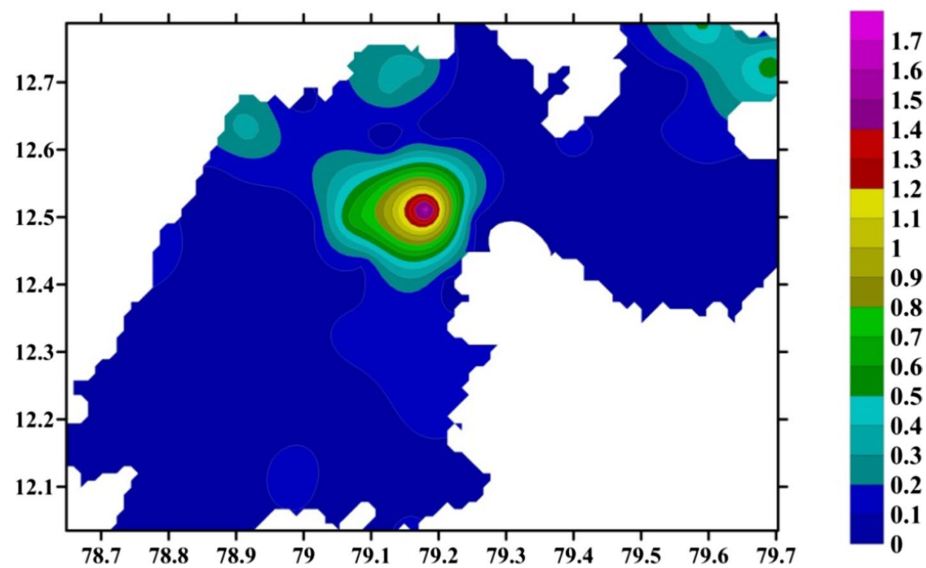


Fig. 16 Spatial distribution of LADD in the study area for adult females

Edaipirai (POL-W37), Sodiambakkam (VEM V60) and Vembakkam (VEM-W61). 30 µg/l is the permissible limit stipulated by USEPA (1982), and only sample from Pulivanandal (CHT-W60) is found to exceed this limit. AERB (AERB 2004) being the only agency with the highest permissible limit of 60 µg/l all the samples easily qualified it. The lowest permissible limit, i.e., 1.9 µg/l, has been recommended by ICRP (1995), only 38 samples fell within the aforesaid limit, and the rest 25 samples exceeded it.

The number of samples that qualified and disqualified the different permissible limits specified by various agencies is shown in Table 5. Figure 11 shows a plot of the frequency distribution of uranium concentration and

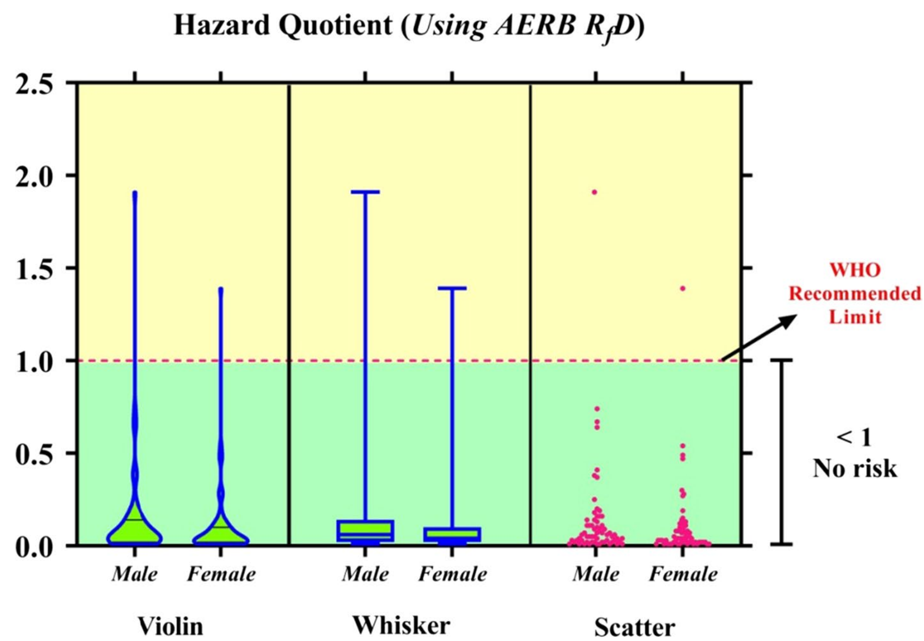


Fig. 17 Frequency distribution of HQ using AERB RfD

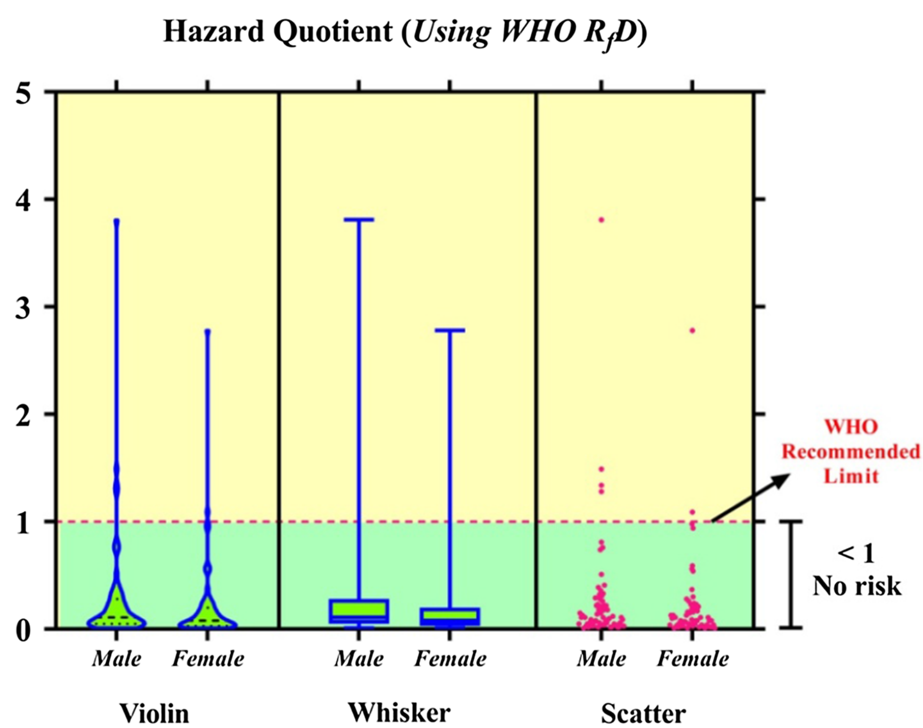


Fig. 18 Frequency distribution of HQ using WHO RfD

Figure 12 shows the spatial distribution of uranium in the study area.

The central region on the spatial map showing denser contours indicates higher concentration of uranium. It is observed that the rocks in this region are mainly charnockites which could considerably contribute to elevated levels of uranium concentration. However, other regions of the same rock type show relatively lower concentration. As the region is not an industrial hub, the only possible reason could be the usage of fertilizers in vast agricultural lands

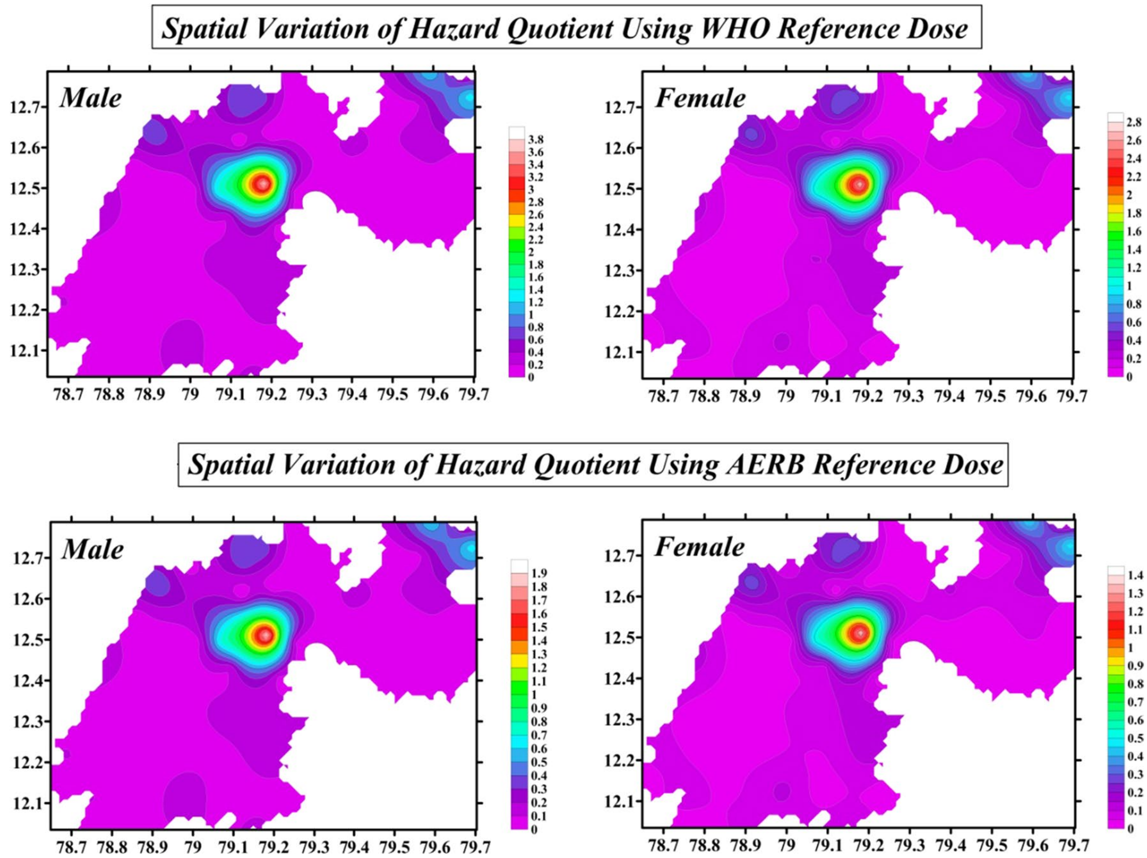


Fig. 19 Spatial distribution of hazard quotient in the study area

Table 6 Statistical parameters—annual whole body dose

Age group	Water intake L per day (Sar et al. 2018)	Dose conversion factor Sv/Bq (Virk 2016)	Annual whole body dose (μSv/year)				
			Range		Mean	Median	SD
			Min	Max			
Infant	0.8	1.40E−07	0.17	44.21	3.29	1.29	6.37
1 year	1.3	1.20E−07	0.24	61.57	4.58	1.79	8.88
5 years	1.7	8.00E−08	0.21	53.68	4.00	1.56	7.74
10 years							
Male	2.4	6.80E−08	0.25	64.42	4.80	1.88	9.29
Female	2.1		0.22	56.36	4.20	1.64	8.12
15 years							
Male	3.3	6.70E−08	0.34	87.27	6.50	2.54	12.58
Female	2.3		0.24	60.82	4.53	1.77	8.77
Adult							
Male	3.7	4.50E−08	0.26	65.72	4.89	1.91	9.47
Female	2.7		0.19	47.96	3.57	1.40	6.91

Lifetime average daily dose

The chemical toxicity risk due to the ingestion of uranium through drinking water is assessed by calculating the life time average daily dose. LADD for this study has been calculated (Table 2) separately for adult male and female using the WIR of 3.7 l day^{-1} and 2.7 l day^{-1}, respectively (USNAS 2004). LADD for adult males varied

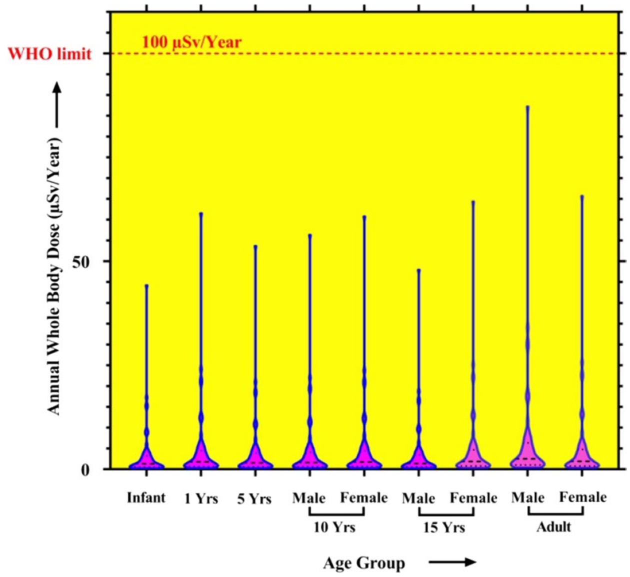


Fig. 20 Violin plot of annual body dose for different age groups

from a minimum of 0.01 µg kg^{-1} day^{-1} to a maximum of 2.29 µg kg^{-1} day^{-1} with an average of 0.17 µg kg^{-1} day^{-1}. On the other hand, LADD in adult females varied from a minimum of 0.01 µg kg^{-1} day^{-1} to a maximum of 1.67 µg kg^{-1} day^{-1} with an average of 0.12 µg kg^{-1} day^{-1}. The LADD in adult male and female is plotted in Figs. 13 and 14, respectively. WHO (2011) has specified a threshold limit of 1 µg kg^{-1} day^{-1} which is seen to be exceeded by the sample from Pulivanandal (CHT –W12). Spatial distribution of LADD in the study area for adult male and female is also shown in Figs. 15 and 16. The rock formations at Pulivanandal are mainly charnockites and may contribute to elevated levels of LADD. Perhaps the usage of fertilizers is also causing a higher uranium concentration in ground water as they tend to easily seep into the ground water table.

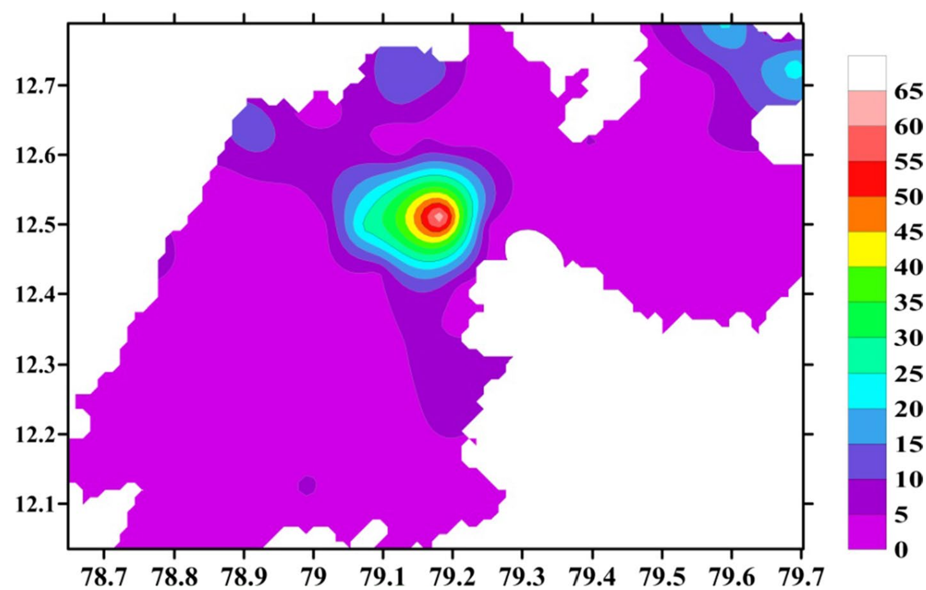
Hazard quotient

The extent to which the ingestion of uranium from ground water can be dangerous is determined by calculating (Table 2) the hazard quotient. The hazard quotient for the samples has been calculated separately for adult males and adult females using two different reference doses (RfD) 0.6 µg kg^{-1} day^{-1} and 1.2 µg kg^{-1} day^{-1} as recommended by WHO (2011) and AERB (2004), respectively. As per WHO guidelines HQ > 1 is considered chemically dangerous (WHO 2011). It is observed that the HQ of the sample from Pulivanandal (CHT-W12) alone exceeds the stipulated safety limit. The distribution of hazard quotient using WHO and AERB RfDs is presented in Figs. 17 and 18, respectively. Spatial contour maps using both AERB and WHO RfDs are shown in Fig. 19. It is noted the region around Pulivanandal (CHT-W12) shows denser contour lines.

Whole body radiation dose

The absorption dose rate is known to vary for each organ in the human body. The whole body dose rate is the total absorption dose rate of the entire body taking into account the individual absorption rate of each organ over a period of

Fig. 21 Spatial variation of annual whole body dose in adult males



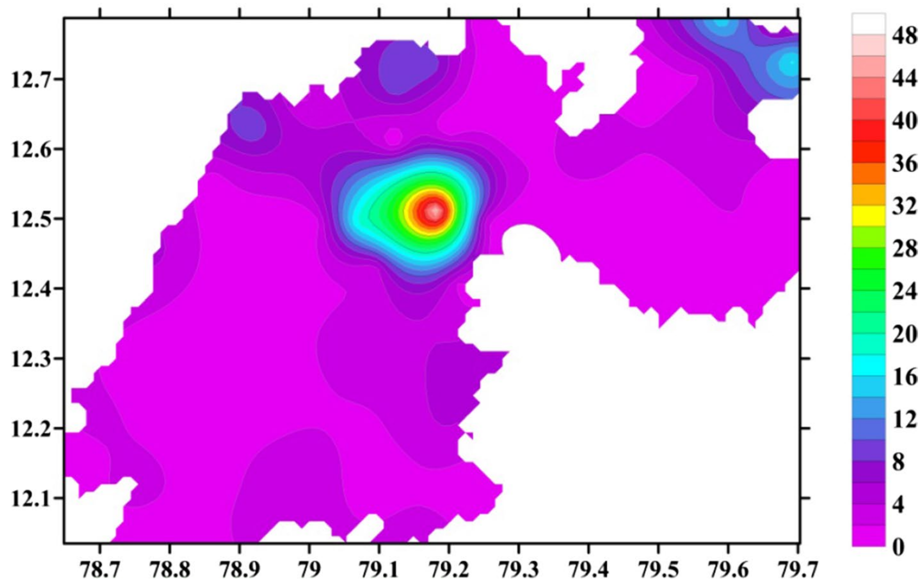


Fig. 22 Spatial variation of annual whole body dose in adult females

one year. Table 7 shows the variation whole body dose rate for different samples. Statistical parameters along with their corresponding conversion factors pertaining to the whole body dose rate for various age groups are shown in Table 6. Fortunately, all the samples are safe with respect to the WHO's stipulated threshold limit of 100 µSv/Year (WHO 2011). The violin plot in Fig. 20 shows the distribution in the study area across different age groups. Contour maps in Figs. 21 and 22 show the spatial variation of annual whole body dose in the study area.

Cumulative whole body dose

The total whole body dose received by an individual during his life time is known as cumulative whole body dose. Considering the average span of a typical adult to be 70 years, the cumulative dose rate has been calculated for both adult male and female (Table 7). For adult males, it is found to range from 18.08 µSv to 4600.34 µSv with a mean of 342.54 µSv. On the other hand, for the adult females, it is found to range from 13.19 µSv to 3357.00 µSv with a mean of 249.96 µSv. Frequency distributions plot of cumulative whole body dose for both male and female is shown in the plot (Fig. 23). Spatial variation of cumulative whole body dose is shown in Figs. 24 and 25 for male and female, respectively.

Lifetime cancer risk

The life time cancer risks for mortality and morbidity were calculated for all the samples (Table 7) using the risk coefficients prescribed by USEPA (2011). For the commonly occurring isotopes (omitting the traces), U^{238}, U^{235} and U^{234} the risk coefficients of mortality are 1.13×10^{-9}, 1.21×10^{-9} and 1.24×10^{-9}, respectively. The risk coefficients of morbidity for U^{238}, U^{235} and U^{234} are 1.73×10^{-9}, 1.88×10^{-9}, and 1.91×10^{-9}, respectively. The statistical parameters of life time cancer risk (mortality and morbidity) for adult male and female are shown in Tables 8 and 9, respectively. The limit of safety as specified by AERB (AERB 2004) is 1.67×10^{-4}, and all the 63 samples qualify to be safe as they all fall within this limit. The USEPA (USEPA 2011) limit is much higher than that of AERB; hence, all the samples easily qualify to be very safe. Violin plots of life time cancer risk (mortality and morbidity) for male and female are shown in Figs. 26 and 27, respectively. The spatial variation of life time cancer risk for U^{238} (mortality and morbidity) is shown in Fig. 28.

Summary

The ground water samples from 63 locations in the district of Tiruvannamalai have been analysed for palatable and potable. The study area was divided into grids using QGIS, and samples were collected from each grid covering the entire region. A lithological map was obtained from Geological Survey of India's website (Bhuvan), and the sampling sites were overlaid on the map to determine the type of rock formation at the sampling site. TDS, pH and EC for the samples were determined using a multi-parameter water tester, and the concentration of uranium was found using an LED fluorimeter. Lifetime average daily dose and hazard quotient were calculated to assess the chemical toxicity, whereas

Table 7 Radiological risk parameters for all the samples

Location ID	Age-wise lifetime whole body radiation dose						Cum whole body dose (adult)		Lifetime cancer risk male						Lifetime cancer risk female					
									U-238		U-235		U-234		U-238		U-235		U-234	
	Infant	1 year	5 years	10 years	15 years	Adult	Male	Female	Mort	Morb	Mort	Morb	Mort	Morb	Mort	Morb	Mort	Morb	Mort	Morb
ANK—W1	2.82	4.49	3.91	4.69	4.43	3.49	335.20	244.61	6.1E−06	9.4E−06	6.6E−06	1.0E−05	6.7E−06	1.0E−05	6.1E−06	9.4E−06	6.6E−06	1.0E−05	6.7E−06	1.0E−05
ANK—W2	0.19	0.31	0.27	0.32	0.3	0.24	22.86	16.68	4.2E−07	6.4E−07	4.5E−07	7.0E−07	4.6E−07	7.1E−07	4.2E−07	6.4E−07	4.5E−07	7.0E−07	4.6E−07	7.1E−07
ARN—W3	0.61	0.97	0.84	1.01	0.95	0.75	72.21	52.69	1.3E−06	2.0E−06	1.4E−06	2.2E−06	1.5E−06	2.2E−06	1.3E−06	2.0E−06	1.4E−06	2.2E−06	1.5E−06	2.2E−06
ARN—W4	0.72	1.15	1	1.2	1.13	0.89	85.72	62.55	1.6E−06	2.4E−06	1.7E−06	2.6E−06	1.7E−06	2.7E−06	1.6E−06	2.4E−06	1.7E−06	2.6E−06	1.7E−06	2.7E−06
ARN—W5	0.44	0.7	0.61	0.73	0.69	0.55	52.32	38.18	9.6E−07	1.5E−06	1.0E−06	1.6E−06	1.1E−06	1.6E−06	9.6E−07	1.5E−06	1.0E−06	1.6E−06	1.1E−06	1.6E−06
ARN—W6	0.58	0.93	0.81	0.97	0.91	0.72	69.13	50.44	1.3E−06	1.9E−06	1.4E−06	2.1E−06	1.4E−06	2.1E−06	1.3E−06	1.9E−06	1.4E−06	2.1E−06	1.4E−06	2.1E−06
CHN—W7	2.2	3.49	3.05	3.66	3.45	2.72	261.08	190.52	4.8E−06	7.3E−06	5.1E−06	8.0E−06	5.3E−06	8.1E−06	4.8E−06	7.3E−06	5.1E−06	8.0E−06	5.3E−06	8.1E−06
CHN—W8	0.25	0.4	0.35	0.42	0.39	0.31	29.78	21.73	5.5E−07	8.4E−07	5.8E−07	9.1E−07	6.0E−07	9.2E−07	5.5E−07	8.4E−07	5.8E−07	9.1E−07	6.0E−07	9.2E−07
CHN—W9	0.21	0.33	0.29	0.34	0.32	0.25	24.46	17.85	4.5E−07	6.9E−07	4.8E−07	7.5E−07	4.9E−07	7.6E−07	4.5E−07	6.9E−07	4.8E−07	7.5E−07	4.9E−07	7.6E−07
CHN—W10	0.57	0.9	0.79	0.95	0.89	0.7	67.53	49.28	1.2E−06	1.9E−06	1.3E−06	2.1E−06	1.4E−06	2.1E−06	1.2E−06	1.9E−06	1.3E−06	2.1E−06	1.4E−06	2.1E−06
CHT—W11	1.52	2.42	2.11	2.53	2.39	1.88	180.58	131.77	3.3E−06	5.1E−06	3.5E−06	5.5E−06	3.6E−06	5.6E−06	3.3E−06	5.1E−06	3.5E−06	5.5E−06	3.6E−06	5.6E−06
CHT—W12	38.68	61.57	53.68	64.42	60.82	47.96	4600.34	3357	8.4E−05	1.3E−04	9.0E−05	1.4E−04	9.3E−05	1.4E−04	8.4E−05	1.3E−04	9.0E−05	1.4E−04	9.3E−05	1.4E−04
CHT—W13	0.8	1.28	1.12	1.34	1.27	1	95.71	69.84	1.8E−06	2.7E−06	1.9E−06	2.9E−06	1.9E−06	3.0E−06	1.8E−06	2.7E−06	1.9E−06	2.9E−06	1.9E−06	3.0E−06
CHY—W14	3.25	5.17	4.51	5.41	5.11	4.03	386.14	281.78	7.1E−06	1.1E−05	7.6E−06	1.2E−05	7.8E−06	1.2E−05	7.1E−06	1.1E−05	7.6E−06	1.2E−05	7.8E−06	1.2E−05
CHY—W15	0.15	0.24	0.21	0.25	0.24	0.19	18.08	13.19	3.3E−07	5.1E−07	3.6E−07	5.5E−07	3.6E−07	5.6E−07	3.3E−07	5.1E−07	3.6E−07	5.5E−07	3.6E−07	5.6E−07
CHY—W16	1.49	2.38	2.07	2.49	2.35	1.85	177.71	129.68	3.3E−06	5.0E−06	3.5E−06	5.4E−06	3.6E−06	5.5E−06	3.3E−06	5.0E−06	3.5E−06	5.4E−06	3.6E−06	5.5E−06
CHY—W17	1.46	2.33	2.03	2.43	2.3	1.81	173.88	126.88	3.2E−06	4.9E−06	3.4E−06	5.3E−06	3.5E−06	5.4E−06	3.2E−06	4.9E−06	3.4E−06	5.3E−06	3.5E−06	5.4E−06
JHL—W18	3.93	6.25	5.45	6.54	6.18	4.87	467.18	340.92	8.6E−06	1.3E−05	9.2E−06	1.4E−05	9.4E−06	1.5E−05	8.6E−06	1.3E−05	9.2E−06	1.4E−05	9.4E−06	1.5E−05
JHL—W19	1.07	1.71	1.49	1.78	1.68	1.33	127.40	92.97	2.3E−06	3.6E−06	2.5E−06	3.9E−06	2.6E−06	4.0E−06	2.3E−06	3.6E−06	2.5E−06	3.9E−06	2.6E−06	4.0E−06
JHL—W20	0.88	1.41	1.23	1.47	1.39	1.1	105.18	76.75	1.9E−06	3.0E−06	2.1E−06	3.2E−06	2.1E−06	3.3E−06	1.9E−06	3.0E−06	2.1E−06	3.2E−06	2.1E−06	3.3E−06
JHL—W21	5.16	8.22	7.17	8.6	8.12	6.4	614.04	448.09	1.1E−05	1.7E−05	1.2E−05	1.9E−05	1.2E−05	1.9E−05	1.1E−05	1.7E−05	1.2E−05	1.9E−05	1.2E−05	1.9E−05
JHL—W22	8.23	13.1	11.42	13.71	12.94	10.2	978.81	714.27	1.8E−05	2.8E−05	1.9E−05	3.0E−05	2.0E−05	3.0E−05	1.8E−05	2.8E−05	1.9E−05	3.0E−05	2.0E−05	3.0E−05

Table 7 (continued)

Location ID	Age-wise lifetime whole body radiation dose						Cum whole body dose (adult)		Lifetime cancer risk male						Lifetime cancer risk female					
									U-238		U-235		U-234		U-238		U-235		U-234	
	Infant	1 year	5 years	10 years	15 years	Adult	Male	Female	Mort	Morb	Mort	Morb	Mort	Morb	Mort	Morb	Mort	Morb	Mort	Morb
JHL—W23	0.39	0.62	0.54	0.65	0.61	0.48	46.26	33.76	8.5E−07	1.3E−06	9.1E−07	1.4E−06	9.3E−07	1.4E−06	8.5E−07	1.3E−06	9.1E−07	1.4E−06	9.3E−07	1.4E−06
KAL—W24	1.09	1.74	1.52	1.82	1.72	1.36	130.06	94.91	2.4E−06	3.7E−06	2.6E−06	4.0E−06	2.6E−06	4.0E−06	2.4E−06	3.7E−06	2.6E−06	4.0E−06	2.6E−06	4.0E−06
KAL—W25	0.47	0.74	0.65	0.78	0.73	0.58	55.51	40.51	1.0E−06	1.6E−06	1.1E−06	1.7E−06	1.1E−06	1.7E−06	1.0E−06	1.6E−06	1.1E−06	1.7E−06	1.1E−06	1.7E−06
KAL—W26	2.25	3.59	3.13	3.75	3.54	2.79	267.99	195.56	4.9E−06	7.5E−06	5.3E−06	8.2E−06	5.4E−06	8.3E−06	4.9E−06	7.5E−06	5.3E−06	8.2E−06	5.4E−06	8.3E−06
KIL—W27	1.37	2.18	1.9	2.28	2.15	1.7	162.71	118.73	3.0E−06	4.6E−06	3.2E−06	5.0E−06	3.3E−06	5.0E−06	3.0E−06	4.6E−06	3.2E−06	5.0E−06	3.3E−06	5.0E−06
KIL—W28	0.35	0.56	0.48	0.58	0.55	0.43	41.48	30.27	7.6E−07	1.2E−06	8.1E−07	1.3E−06	8.3E−07	1.3E−06	7.6E−07	1.2E−06	8.1E−07	1.3E−06	8.3E−07	1.3E−06
KIL—W29	4.15	6.61	5.76	6.91	6.53	5.15	493.66	360.24	9.1E−06	1.4E−05	9.7E−06	1.5E−05	9.9E−06	1.5E−05	9.1E−06	1.4E−05	9.7E−06	1.5E−05	9.9E−06	1.5E−05
KIL—W30	3.63	5.77	5.03	6.04	5.7	4.49	431.13	314.61	7.9E−06	1.2E−05	8.5E−06	1.3E−05	8.7E−06	1.3E−05	7.9E−06	1.2E−05	8.5E−06	1.3E−05	8.7E−06	1.3E−05
PER—W31	0.31	0.49	0.43	0.52	0.49	0.38	36.80	26.85	6.7E−07	1.0E−06	7.2E−07	1.1E−06	7.4E−07	1.1E−06	6.7E−07	1.0E−06	7.2E−07	1.1E−06	7.4E−07	1.1E−06
PER—W32	1.16	1.84	1.61	1.93	1.82	1.44	137.83	100.58	2.5E−06	3.9E−06	2.7E−06	4.2E−06	2.8E−06	4.3E−06	2.5E−06	3.9E−06	2.7E−06	4.2E−06	2.8E−06	4.3E−06
PER—W33	0.25	0.39	0.34	0.41	0.39	0.31	29.46	21.5	5.4E−07	8.3E−07	5.8E−07	9.0E−07	5.9E−07	9.1E−07	5.4E−07	8.3E−07	5.8E−07	9.0E−07	5.9E−07	9.1E−07
PUD—W34	1.05	1.66	1.45	1.74	1.64	1.3	124.32	90.72	2.3E−06	3.5E−06	2.4E−06	3.8E−06	2.5E−06	3.9E−06	2.3E−06	3.5E−06	2.4E−06	3.8E−06	2.5E−06	3.9E−06
PUD—W35	0.49	0.79	0.68	0.82	0.78	0.61	58.70	42.84	1.1E−06	1.7E−06	1.2E−06	1.8E−06	1.2E−06	1.8E−06	1.1E−06	1.7E−06	1.2E−06	1.8E−06	1.2E−06	1.8E−06
POL—W36	7.74	12.32	10.74	12.89	12.17	9.6	920.54	671.74	1.7E−05	2.6E−05	1.8E−05	2.8E−05	1.9E−05	2.9E−05	1.7E−05	2.6E−05	1.8E−05	2.8E−05	1.9E−05	2.9E−05
POL—W37	15.12	24.07	20.98	25.18	23.77	18.74	1798.00	1312.05	3.3E−05	5.0E−05	3.5E−05	5.5E−05	3.6E−05	5.6E−05	3.3E−05	5.0E−05	3.5E−05	5.5E−05	3.6E−05	5.6E−05
POL—W38	0.42	0.67	0.58	0.7	0.66	0.52	49.98	36.47	9.2E−07	1.4E−06	9.8E−07	1.5E−06	1.0E−06	1.6E−06	9.2E−07	1.4E−06	9.8E−07	1.5E−06	1.0E−06	1.6E−06
POL—W39	0.3	0.48	0.42	0.5	0.47	0.37	35.73	26.08	6.6E−07	1.0E−06	7.0E−07	1.1E−06	7.2E−07	1.1E−06	6.6E−07	1.0E−06	7.0E−07	1.1E−06	7.2E−07	1.1E−06
TEL—W40	0.96	1.52	1.33	1.59	1.5	1.19	113.68	82.96	2.1E−06	3.2E−06	2.2E−06	3.5E−06	2.3E−06	3.5E−06	2.1E−06	3.2E−06	2.2E−06	3.5E−06	2.3E−06	3.5E−06
TEL—W41	0.45	0.71	0.62	0.75	0.71	0.56	53.39	38.96	9.8E−07	1.5E−06	1.1E−06	1.6E−06	1.1E−06	1.7E−06	9.8E−07	1.5E−06	1.1E−06	1.6E−06	1.1E−06	1.7E−06
THD—W42	0.18	0.28	0.24	0.29	0.28	0.22	20.95	15.29	3.8E−07	5.9E−07	4.1E−07	6.4E−07	4.2E−07	6.5E−07	3.8E−07	5.9E−07	4.1E−07	6.4E−07	4.2E−07	6.5E−07
THD—W43	1.87	2.97	2.59	3.11	2.94	2.32	222.26	162.19	4.1E−06	6.2E−06	4.4E−06	6.8E−06	4.5E−06	6.9E−06	4.1E−06	6.2E−06	4.4E−06	6.8E−06	4.5E−06	6.9E−06

Table 7 (continued)

Location ID	Age-wise lifetime whole body radiation dose						Cum whole body dose (adult)		Lifetime cancer risk male						Lifetime cancer risk female					
									U-238		U-235		U-234		U-238		U-235		U-234	
	Infant	1 year	5 years	10 years	15 years	Adult	Male	Female	Mort	Morb	Mort	Morb	Mort	Morb	Mort	Morb	Mort	Morb	Mort	Morb
THD—W44	1.13	1.79	1.56	1.88	1.77	1.4	134.00	97.78	2.5E−06	3.8E−06	2.6E−06	4.1E−06	2.7E−06	4.2E−06	2.5E−06	3.8E−06	2.6E−06	4.1E−06	2.7E−06	4.2E−06
THD—W45	2.25	3.59	3.13	3.75	3.54	2.79	267.99	195.56	4.9E−06	7.5E−06	5.3E−06	8.2E−06	5.4E−06	8.3E−06	4.9E−06	7.5E−06	5.3E−06	8.2E−06	5.4E−06	8.3E−06
THD—W46	0.72	1.14	1	1.19	1.13	0.89	85.29	62.24	1.6E−06	2.4E−06	1.7E−06	2.6E−06	1.7E−06	2.6E−06	1.6E−06	2.4E−06	1.7E−06	2.6E−06	1.7E−06	2.6E−06
THD—W47	0.96	1.52	1.33	1.59	1.51	1.19	113.90	83.11	2.1E−06	3.2E−06	2.2E−06	3.5E−06	2.3E−06	3.5E−06	2.1E−06	3.2E−06	2.2E−06	3.5E−06	2.3E−06	3.5E−06
THD—W48	3.3	5.26	4.59	5.5	5.2	4.1	392.95	286.75	7.2E−06	1.1E−05	7.7E−06	1.2E−05	7.9E−06	1.2E−05	7.2E−06	1.1E−05	7.7E−06	1.2E−05	7.9E−06	1.2E−05
TIR—W49	1.85	2.94	2.57	3.08	2.91	2.29	219.82	160.41	4.0E−06	6.2E−06	4.3E−06	6.7E−06	4.4E−06	6.8E−06	4.0E−06	6.2E−06	4.3E−06	6.7E−06	4.4E−06	6.8E−06
TIR—W50	0.56	0.89	0.77	0.93	0.88	0.69	66.36	48.43	1.2E−06	1.9E−06	1.3E−06	2.0E−06	1.3E−06	2.1E−06	1.2E−06	1.9E−06	1.3E−06	2.0E−06	1.3E−06	2.1E−06
TIR—W51	1.2	1.91	1.67	2	1.89	1.49	143.04	104.38	2.6E−06	4.0E−06	2.8E−06	4.4E−06	2.9E−06	4.4E−06	2.6E−06	4.0E−06	2.8E−06	4.4E−06	2.9E−06	4.4E−06
TIR—W52	2.69	4.27	3.73	4.47	4.22	3.33	319.36	233.05	5.9E−06	9.0E−06	6.3E−06	9.7E−06	6.4E−06	9.9E−06	5.9E−06	9.0E−06	6.3E−06	9.7E−06	6.4E−06	9.9E−06
TUR—W53	2.92	4.64	4.05	4.86	4.59	3.62	346.80	253.07	6.4E−06	9.7E−06	6.8E−06	1.1E−05	7.0E−06	1.1E−05	6.4E−06	9.7E−06	6.8E−06	1.1E−05	7.0E−06	1.1E−05
TUR—W54	3.19	5.07	4.42	5.31	5.01	3.95	379.13	276.66	7.0E−06	1.1E−05	7.4E−06	1.2E−05	7.6E−06	1.2E−05	7.0E−06	1.1E−05	7.4E−06	1.2E−05	7.6E−06	1.2E−05
VAN—W55	0.22	0.35	0.3	0.36	0.34	0.27	25.84	18.86	4.7E−07	7.3E−07	5.1E−07	7.9E−07	5.2E−07	8.0E−07	4.7E−07	7.3E−07	5.1E−07	7.9E−07	5.2E−07	8.0E−07
VAN—W56	0.3	0.47	0.41	0.49	0.47	0.37	35.20	25.69	6.5E−07	9.9E−07	6.9E−07	1.1E−06	7.1E−07	1.1E−06	6.5E−07	9.9E−07	6.9E−07	1.1E−06	7.1E−07	1.1E−06
VAN—W57	1.85	2.95	2.57	3.09	2.91	2.3	220.35	160.8	4.0E−06	6.2E−06	4.3E−06	6.7E−06	4.4E−06	6.8E−06	4.0E−06	6.2E−06	4.3E−06	6.7E−06	4.4E−06	6.8E−06
VEM—W58	0.58	0.92	0.8	0.96	0.91	0.72	68.59	50.05	1.3E−06	1.9E−06	1.4E−06	2.1E−06	1.4E−06	2.1E−06	1.3E−06	1.9E−06	1.4E−06	2.1E−06	1.4E−06	2.1E−06
VEM—W59	2.33	3.7	3.23	3.87	3.66	2.88	276.61	201.85	5.1E−06	7.8E−06	5.4E−06	8.4E−06	5.6E−06	8.6E−06	5.1E−06	7.8E−06	5.4E−06	8.4E−06	5.6E−06	8.6E−06
VEM—W60	13.62	21.68	18.9	22.68	21.42	16.89	1619.76	1181.99	3.0E−05	4.5E−05	3.2E−05	4.9E−05	3.3E−05	5.0E−05	3.0E−05	4.5E−05	3.2E−05	4.9E−05	3.3E−05	5.0E−05
VEM—W61	13.01	20.71	18.05	21.66	20.46	16.13	1547.13	1128.99	2.8E−05	4.3E−05	3.0E−05	4.7E−05	3.1E−05	4.8E−05	2.8E−05	4.3E−05	3.0E−05	4.7E−05	3.1E−05	4.8E−05
WAR—W62	2.11	3.37	2.93	3.52	3.33	2.62	251.51	183.53	4.6E−06	7.1E−06	4.9E−06	7.7E−06	5.1E−06	7.8E−06	4.6E−06	7.1E−06	4.9E−06	7.7E−06	5.1E−06	7.8E−06
WAR—W63	7.49	11.92	10.39	12.47	11.77	9.28	890.33	649.7	1.6E−05	2.5E−05	1.8E−05	2.7E−05	1.8E−05	2.8E−05	1.6E−05	2.5E−05	1.8E−05	2.7E−05	1.8E−05	2.8E−05

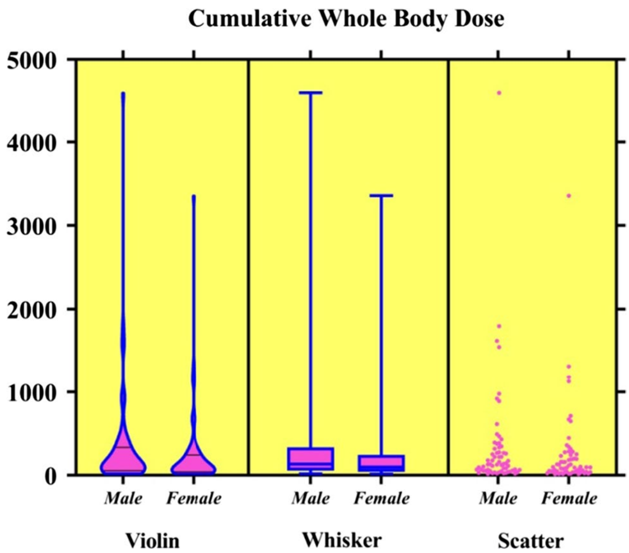


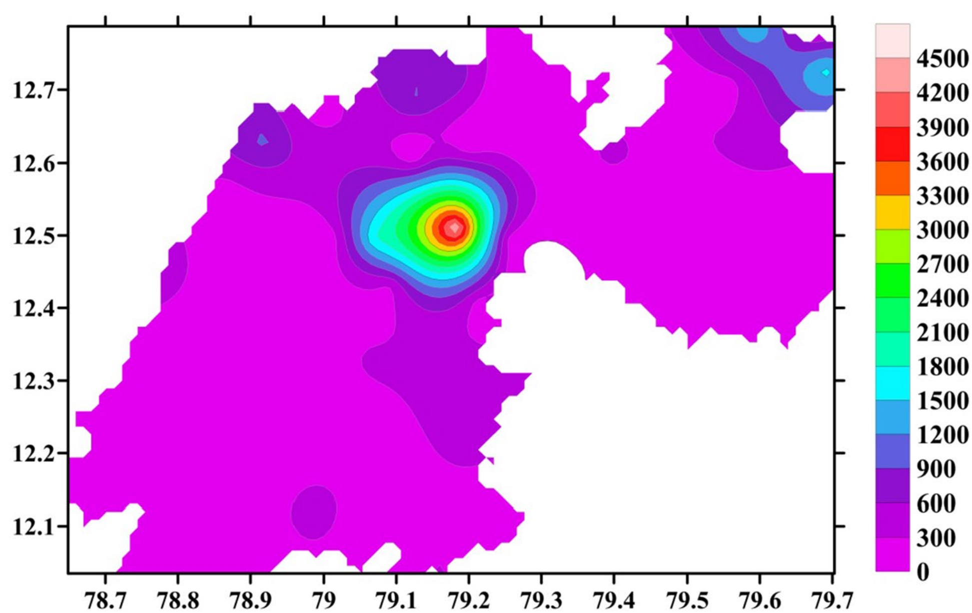
Fig. 23 Frequency distribution of cumulative whole body dose

whole body radiation dose, cumulative whole body dose and excess cancer risk were calculated to assess the radioactive risk. To study the distribution of parameters in the samples, Violin, Whisker and Scatter plots were drawn. Using Surfer spatial contour maps for each parameter were plotted. Each parameter was compared with the limits of safety specified by different agencies.

Based on AERB guidelines of safety, all the samples showed the concentration of uranium to be below than 60 µg/l. However, some samples exceeded USEPA (2011), WHO (2011), UNSCEAR (1982) and ICRP (1995) limits. Sample from Pulivanandal (CHT-W12) was found to exceed the WHO limit for both LADD and HQ. Carcinogenic risk assessment done using whole body radiation dose, cumulative whole body dose and life time cancer risk revealed that the water samples are potable.

As there are no industries, tanneries or mills in the region around Pulivanandal (CHT-W12), the possible reason for higher concentration of uranium could be attributed to excessive use of fertilizers. Agriculture being the main occupation of the local population, farmers grow short-term crops and apply fertilizers to get better yields. More information could be obtained on conducting a detailed study of the rock formation, soil types and anthropogenic activities in this region.

Fig. 24 Spatial variation of cumulative whole body dose in adult males



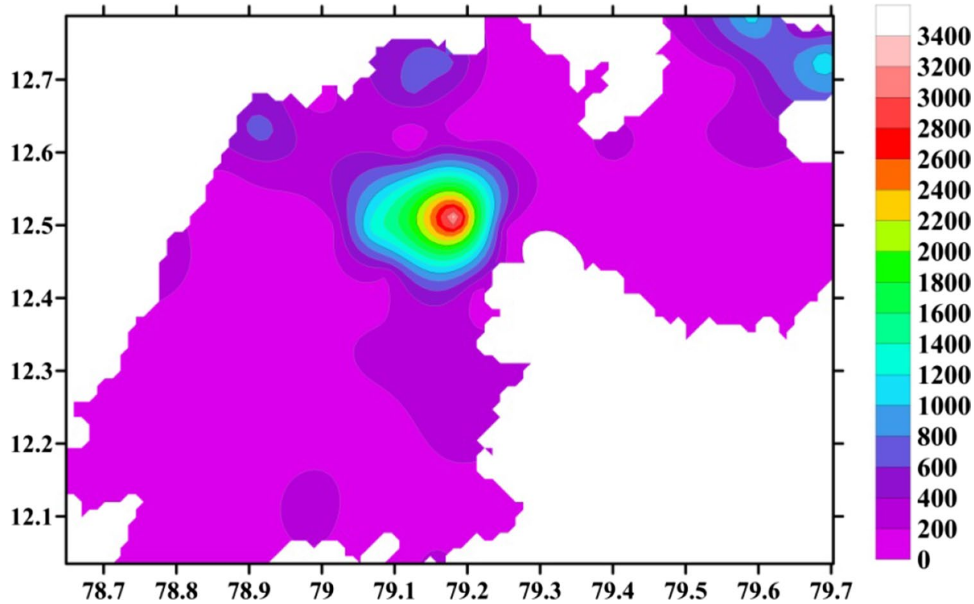


Fig. 25 Spatial variation of cumulative whole body dose in adult females

Table 8 Lifetime cancer risk (male)—statistical parameters

	Lifetime cancer risk (male)					
	U238		U235		U234	
	Mortality	Morbidity	Mortality	Morbidity	Mortality	Morbidity
Min	4.54E−07	6.95E−07	4.86E−07	7.55E−07	4.98E−07	7.67E−07
Max	1.16E−04	1.77E−04	1.24E−04	1.92E−04	1.27E−04	1.95E−04
Mean	8.60E−06	1.32E−05	9.21E−06	1.43E−05	9.44E−06	1.45E−05
Median	3.36E−06	5.15E−06	3.60E−06	5.60E−06	3.69E−06	5.69E−06
SD	1.67E−05	2.55E−05	1.78E−05	2.77E−05	1.83E−05	2.81E−05

Table 9 Lifetime cancer risk (female)—statistical parameters

	Lifetime cancer risk (female)					
	U238		U235		U234	
	Mortality	Morbidity	Mortality	Morbidity	Mortality	Morbidity
Min	3.31E−07	5.07E−07	3.55E−07	5.51E−07	3.64E−07	5.60E−07
Max	8.43E−05	1.29E−04	9.03E−05	1.40E−04	9.25E−05	1.42E−04
Mean	6.28E−06	9.61E−06	6.72E−06	1.04E−05	6.89E−06	1.06E−05
Median	2.46E−06	3.76E−06	2.63E−06	4.09E−06	2.69E−06	4.15E−06
SD	1.22E−05	1.86E−05	1.30E−05	2.02E−05	1.33E−05	2.05E−05

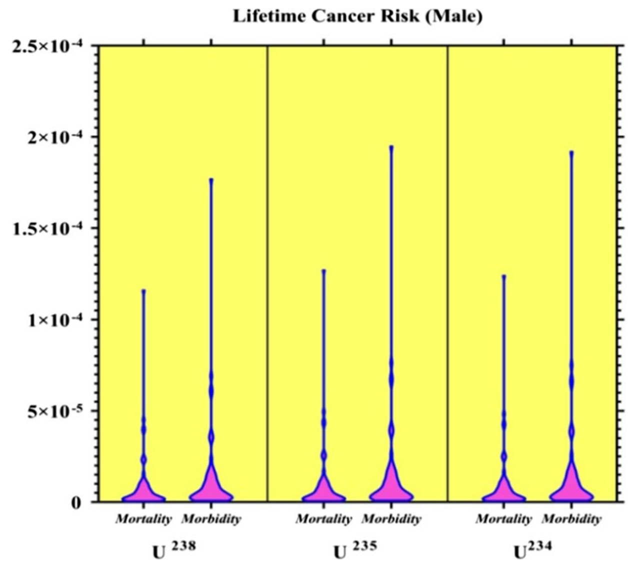


Fig. 26 Distribution of life time cancer risk (males) in the samples

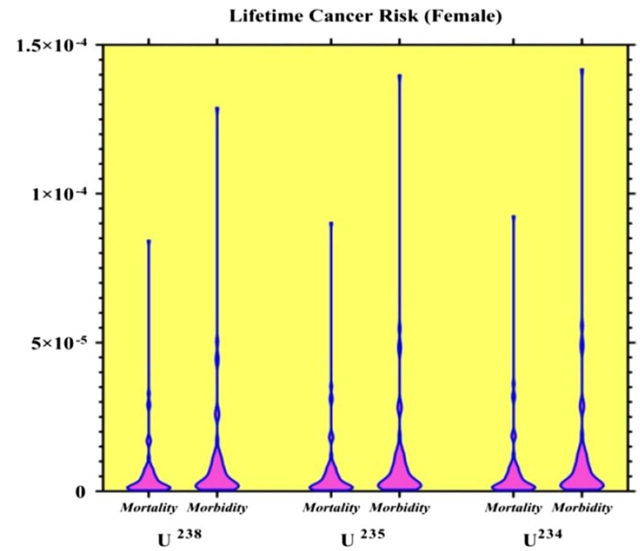


Fig. 27 Distribution of life time cancer risk (females) in the samples

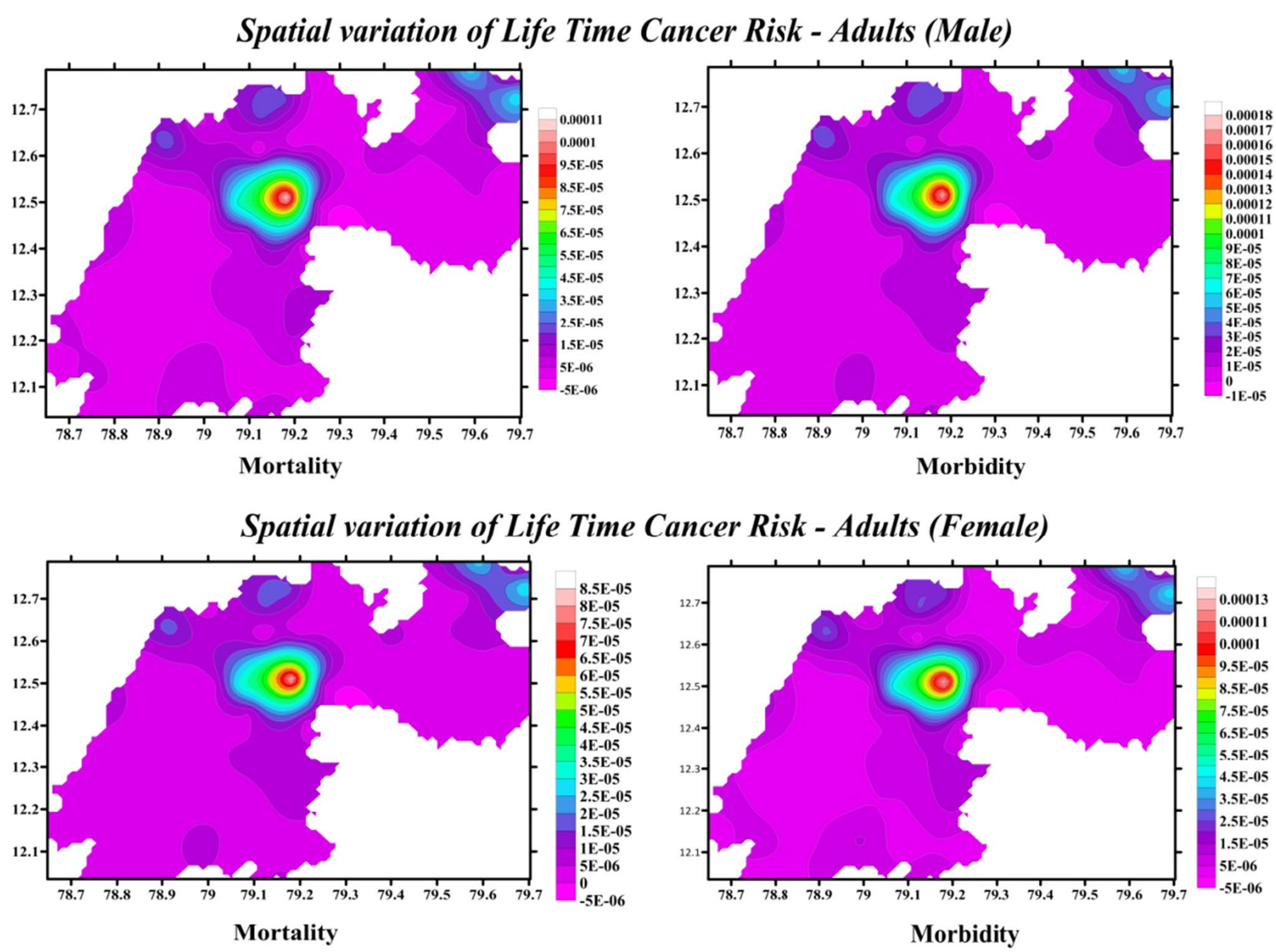


Fig. 28 Spatial distribution of life time cancer risk in the study area

Acknowledgements The authors are extremely grateful to the Dr. B. Venkataraman, Director IGCAR Kalpakkam, for permitting them to utilize the laboratory for this study.

Funding No funding was received to assist with the preparation of this manuscript.

Declarations

Conflict of interest This paper work does not have any conflict of interest and ethical statement.

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References

AERB (Atomic Energy Regulatory Board) (2004) Department of Atomic Energy, Drinking Water Specification in India; Government of India

Bhangare RC, Tiwari M, Ajmal PY, Sahu SK, Pandit GG (2013) Laser flourimetric analysis of uranium in water from Vishakapatnam and estimation of health risk. Radiat Protect Environ 36(3):128–132

BIS (Bureau of Indian Standards) (2012) Indian standard drinking water—specification (second revision) IS10500:2012

DSH (District Statistical Handbook) (2018–2019) Department of Economics and Statistics, Tiruvannamalai, Government of Tamil Nadu; released by the District Collectorate, Tiruvannamalai District, Tamil Nadu. Geological Survey of India's Website, Government of India. http://bukosh.gsi.gov.in/Bhukosh

ICRP (1995) Age-dependent doses to the members of the public from intake of radionuclides—part 5 compilation of ingestion and inhalation coefficients. ICRP Publication 72. Ann. ICRP 26(1)

Report no. ESSO/IMD/HS/R.F. REPORT/02 (2014)/18, Rainfall statistics of India 2013, IndiaMeteorological Department (Ministry of Earth Sciences) by Dr. (Mrs.) Surinder Kaur and M.K. Purohit

Sar SK, Diwan V, Biswas S, Singh S, Sahu M, Jindal MK, Arora A (2018) Study of Uranium levels in underground water of Balod district of Chattisgarh State, India and Assessment of Health Risk. J Hum Ecol Risk Assess 24(3):691–698

UNSCEAR (United Nations Scientific committee on the Effects of Atomic Radiation) (1982) Ionizing radiation: sources and biological effects. New York, United Nations

USEPA (United States Environmental Protection Agency) (1991) "Review of RSC analysis", Report prepared by Wade Miller Associates, Inc. for the United States Environmental Protection Agency, Washington, DC

USEPA (United States Environmental Protection Agency) (2011) Edition of the drinking water standards and health advisories. EPA 820-R-11-002, Office of water, USEPA, Washington, DC

USNAS (United States National Academy of Science) (2004) Institute of medicine, food and nutrition board dietary reference intakes for water, potassium, sodium, chloride and sulphate. The National Academics Press, Washington, DC

Virk HS (2016) Measurement of concentration of natural uranium in ground waters of Bathinda District (S. Punjab) for the assessment of Annual Effective Dose. Glob J Hum Soc Sci 16:1

WHO (World Health Organisation) (2011) Guidelines for drinking—water quality, 4th edn. World Health Organisation, Geneva

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