J Radioanal Nucl Chem (2015) 303:601–613
DOI 10.1007/s10967-014-3353-1

Characterization of uranium and its progenies in drinking water and assessment of dose to public around a NHBRA, Odisha, India

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Received: 6 May 2014 / Published online: 27 July 2014

Abstract Present work deals with the distribution study of naturally occurring radioactive materials in drinking water samples around Orissa sands complex, Odisha, India and assessment of the comprehensive ingestion dose to members of the public. The mean total effective dose to member of public is found to be 67.1 μSv/y with a range of 13.2–198.5 μSv/y. The average effective dose is below the reference level of 100 μSv/y and also comparable with the range of global annual ingestion dose value reported worldwide. The activity concentration in drinking water reported here is due to natural distribution of radioanuclides.

Keywords Effective dose · OSCOM · NORM · Drinking water intake · Laser fluorimetry · Natural high background radiation area (NHBRA)

Introduction

Naturally occurring radioactive materials (NORM) are ubiquitous in the environment. Apart from the terrestrial radionuclides (and their decay products) of primordial origin with half-lives comparable to the age of the Earth (about 3 billion years), NORM include cosmic and cosmogenic radionuclides which consists of primary charged and neutral particles that bombard the Earth's atmosphere and the secondary particles generated by the primary particles in the Earth's atmosphere. Natural radionuclides present in every compartment of environment with wide variation in concentration depending on regional geological formation, prevailing environmental conditions etc. NORM in the environment mainly arises due to ^{238}U and ^{232}Th series isotopes and ^{40}K. Natural radiation is the largest contributor to the total radiation dose to population. About 20 % of the natural radiation dose is due to external radiation from terrestrial radioactivity [1]. The levels of terrestrial radiation are related to the soil type and consequently to the parent material (type of rocks) [1]. The radionuclides that are present in soils and host rocks can be leached to the corresponding aquifers depending upon their solubility and geochemistry and hence prevails in surface and ground water bodies. There have been reported studies worldwide regarding the occurrence of natural radioactivity in drinking water from different sources [2–5, 6]. Water intake is an essential part of human diet, may contribute to chronic natural radioactivity exposure. Drinking water consumption may be crucial in the areas prone to exposure of natural alpha emitters [1]. Groundwater quality is severely affected by the inherent bedrock and soil characteristics of the area. The areas with granitic host rock contains inherent high level of natural radioactivity and hence groundwater quality is severely affected by the inherent bedrock (e.g. High level of radioactivity granitic host rocks [7]) and soil characteristics of the area. Radiological characterisation of drinking water, by estimating the concentration of these naturally occurring radioactive elements is pivotal to assess the potential radiological impact and dose to the population inhabited in that area.

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Few regions in China, Iran, Brazil and India, etc. however were known as natural high background radiation areas (NHBRA) due to monazite deposits where very high terrestrial radiation dose values were reported which have radiation levels (10–100) times higher than the normal background [1]. Details of other NHBRA areas worldwide were discussed elsewhere [8]. Areas such as Guarapari, the coastal region of Espirito Santo and the Morro Do Forro in Minas Gerais in Brazil [9–13]; Yangjiang, in China [14, 15]; the southwest coast of India [16–19]; Ramsar and Mahallat in Iran [20, 21]; in the United States and Canada [22], and in some other counties [1] are well known for their high background radiation due to the local geology. Like in Brazil, China and coastal lines of India, the monazite placer deposit of these regions plays a host to high background radiation as monazite and zircon in rich in terrestrial radionuclides of thorium and uranium. Ramsar, Iran is among the list due to its high level of radium in soil/water and radon in air which contributes to the high background radiation exposure. In India namely Ullal in Karnataka [23], Kalpakkam [24] in Tamil Nadu, coastal parts of Tamil Nadu and Kerala state and the southwestern coast of India are known high background radiation areas [17, 18]. Inhabitants of HBRAs are subjected to high natural radiation exposure which is inevitable. The major source responsible for this exposure is the primordial radionuclides in earth crust like ^{238}U series and ^{232}Th series and ^{40}K. These HBRAs have been under study for many years in order to determine the risks and effects of long-term, low-level and natural radiation exposure [25]. The natural radioactivity scenario may modify drastically due to uncontrolled anthropogenic activities. Mineral mining is one of the anthropogenic practices which has the potential to redistribute the minerals in the adjoining area and may enhance natural radioactivity if adequate safety measures are not implemented [26, 27]. Extraction of ores and subsequent processing technology may lead to enhanced levels of NORM in the surrounding areas and hence mining activities in that particular area may redefine the radiological scenario and modify the environment. The continuous environmental surveillance has been effective in controlling the environmental release of radioactivity since the commencement of the operation.

India is blessed with vast resources of rare earths in the form of monazite found in the beach sands of Kerala, Tamil Nadu and Odisha coast. Indian Rare Earths Limited (IREL), under the Department of Atomic Energy, has been operational in those areas since decades to produce rare earths and thorium from monazite. In India, the beach placer deposit at Chhatrapur coast of Orissa, Manavalakurichi in Tamil Nadu and Chavara in Kerala known for their enhanced radiogenic environment. Orissa Sands Complex (OSCOM) of Indian Rare Earth Limited is located near Mathikhalo village, in Chhatrapur taluk, Ganjam district, Odisha, India and has a mineral separation plant (MSP) for the production of ilmenite, garnet, silemenite, monazite, rutile, zircon, etc. [28]. The area is extended over 20 km ranging from north–east to south–west with an average width of more than 1.5 km. This region has Bay of Bengal in its southern side and Eastern Ghat Groups of rocks in the northern and north western side. Rushikulya River serves as the main drainage system of this region, which originates from Eastern Ghat and joins the sea at Chhatrapur region. Well developed sand dunes are there in this region, parallel to the sea coast [29]. The average heavy mineral concentration in sands from this region varies between 18–23 vol% [30]. The heavy minerals present in the sand are silemenite, ilmenite, zircon, garnet, rutile and monazite. Other reported values of natural gamma radiation survey and estimation of terrestrial natural radioactivity concentration such as ^{238}U, ^{232}Th and ^{40}K in the study area were discussed in the following studies [8, 29, 31, 32].

Study of the natural radioactivity levels in various environmental matrices is of great radiological significance for establishment of natural radiation and dose rate levels around a beach sand mining facility at Odisha and finding out the main radionuclides of concern posing threat to the general public inhabiting this region. In addition, this aids in planning and development of appropriate monitoring and surveillance programme. Also it will generate a database which will be helpful in establishing a NORM map for the study area. This map will be used as reference information to assess any changes in the radioactivity levels in the course of operation of mining activities. Objective of the present study is to appraise the comprehensive radiation dose to the member of public residing around a NHBRA like Chattrapur, Odisha, India due natural radioanuclides in drinking water intake since NHBRA areas are associated with elevated level of natural radioactivity. The present work deals with measurement of the radionuclide concentrations like total uranium, ^{226}Ra, ^{210}Po and ^{210}Pb in drinking water around the study area and assessment of the comprehensive ingestion dose to members of the public. These are the most significant radionuclides typically found in drinking water with respect to radiation dose evaluation. Though the study area has enhanced level of thorium in natural radioactivity concentration due to its granitic host rock but since thorium is water insoluble we concentrated mainly on uranium and its daughters.

Study area and sampling

The study area is one of the natural high background radiation area of India, situated around the monazite rich placer deposit in Chatrapur, Ganjam district (19°15′–19°21′N, 84°3′–84°55′E) of Odisha state in eastern India.

Fig. 1 Study area in the map of Ganjam district, Odisha and Google map of the study area showing zoning during sampling and survey

The high natural background area is along the coast, about 20 km long and 2 km wide. Orissa Sands Complex (OSCOM) is located near Mathikhalo village, in Chatrapur taluk, Ganjam district, Odisha and India Rare Earth Limited (IREL) operates here to recover heavy minerals from the beach sand. The facility consists of a dredging and wet concentrator plant, mineral separation plant (MSP) and a thorium plant commissioned in 1992. The MSP is used for the separation of heavy minerals like sillimanite, monazite, rutile and zircon, etc. The people residing around the area are subjected to higher levels of natural background radiation due to presence of naturally enhanced radionuclide levels in the environment [8].

Location map and zoning of the sampling area is shown in Fig. 1. The surrounding environment up to 10 km around OSCOM was selected for sampling because within this region the impact of the radionuclides will be significant if any. The selected area was divided into three zones with respect to the facility and drinking water samples of one liter each were collected from the surrounding villages of that area following International Atomic Energy Agency (IAEA) recommendation and guideline [33]. Drinking water samples of 24 numbers were collected from both surface and ground water resources (mostly tube well and bore well water) in pre acid cleaned containers in order to avoid wall absorption. Water quality parameters like pH, electrical conductivity (EC) and total dissolved solid (TDS) were measured insitu, using portable handheld instruments. Drinking water samples were filtered using 0.45 μm filter paper for the removal of suspended particulate matter and processed accordingly for the determination of natural radioelement of uranium and 238U progenies of ^{210}Po, ^{210}Pb and ^{226}Ra.

Analytical procedure

Estimation of total uranium

Drinking water samples were directly analysed for total uranium concentration by laser uranium analyser. Laser fluorimetry is one of the quick, sensitive and reliable

methods of estimating uranium in ultra trace level in aqueous environmental samples without any sample pretreatment. The fluorescence of uranyl complex was measured in the sample directly after addition of sodium pyrophosphate as fluorescence enhancing as well as complexing reagent. The signal was measured in a photomultiplier tube. The water samples were analyzed by standard addition method, in order to avoid the matrix effect. The minimum detectable activity (MDA) of the method is 0.2 μg/l. The details of the method and analytical procedure are found elsewhere [34, 35]. The recovery of spiked uranium is 70–94 %.

Estimation of ^{210}Po

Generally the activity concentration in water bodies is typically low due to strong binding of polonium with sediment [36]. For the estimation of ^{210}Po in drinking water, samples were first digested with concentrated HNO_3 and HCl followed by autodeposition on silver planchette and subsequently counted in alpha spectrometry. Ascorbic acid was added to the solution in order to reduce iron and minimize interference during autodeposition [37]. As the alpha energy is used for detection and measurement, the ^{210}Po requires separation from the bulk matrix and preparation of a thin, uniform monomolecular source for accurate measurement [38]. Auto deposited silver disk samples were counted in 450 mm^2 Passivated Ion Implanted Planar Silicon alpha detector (PIPS ULTRA, bias 50 V). ^{209}Po tracer was added to the sample to compute the yield. Results were corrected to the time of sample collection in order to account the ^{210}Po decay. Details about the alpha detector, optimization and counting is given elsewhere [39, 40]. The MDA of the method is 1.5 mBq. The tracer recovery of ^{209}Po is 75–85 %.

Estimation of ^{210}Pb

^{210}Pb was measured by gross beta counting system after radiochemical separation [41]. After the autodeposition of ^{210}Po, the solution was treated with concentrated HNO_3 and Pb carrier was added along with H_2SO_4 in order to get the $PbSO_4$ precipitate. The precipitate was then dissolved in hot saturated solution of ammonium acetate. Na_2S solution was added to get PbS precipitate. The precipitate was then dissolved with conc. HNO_3 and H_2SO_4 was added to get the $PbSO_4$ precipitate. The precipitate was then transferred to an Al planchette and after drying, kept for about 35 days to ensure secular equilibrium of ^{210}Pb with its daughter product ^{210}Bi. The planchets were then counted for beta activity by using a silicon detector based simultaneous alpha beta counter (Doza, YMφ-2000) and ^{210}Pb activity was calculated by using the following formula, (Eq. 1), [42].

$$\mathrm{CPb} = \frac{A_t}{[(1 - \mathrm{e}^{-\lambda \mathrm{Bi} t})\eta w]}, \quad (1)$$

where A_t is the net count rate (s^{-1}), λ_{Bi} is the ^{210}Bi decay constant (min^{-1}), t is the ^{210}Bi in-growth time (min), η is the detection efficiency for ^{210}Bi and w is the sample dry weight (kg). The MDA of the method is 0.2 mBq. The chemical yield of ^{210}Pb is up to 80 %.

Estimation of ^{226}Ra

The activity concentration of radium in ground water mainly depends upon the chemical and physical process like adsorption, desorption, complex formation and precipitation-dissolution which again depends upon the chemical composition of groundwater. The concentration of ^{226}Ra in drinking water was estimated by emanometry technique [43]. Filtered water samples were treated with conc. HNO_3 and pre-concentrated prior transferring to the radon bubbler. The radon in the water samples was removed by a vacuum pump and then the water in the bubbler was allowed to stand for 10–20 days in order to build up of fresh radon from the ^{226}Ra present in the sample. The radon gas was then collected in a scintillation cell and counted through a photo multiplier assembly for alpha activity. The ^{226}Ra content of the solution can be derived as follows (Eq. 2) by using the appropriate build up and decay factors for ^{222}Rn, which are a function of the buildup period and decay constant of ^{222}Rn. The MDA of the method is 3.5 mBq.

$$^{226}\mathrm{Ra} = \frac{-6.967 \times 10^{-2} \times D}{[V \times E \times \mathrm{e}^{-\lambda T} \times (1 - \mathrm{e}^{-\lambda t}) \times (1 - \mathrm{e}^{-\lambda \theta})]} \left(\frac{\mathrm{Bq}}{1}\right), \quad (2)$$

where D—Net alpha counts obtained ($D = c - b$, c is the total counts, and b is the background counts), V—Volume of water in radon bubbler (ml), E—Efficiency of the scintillation cell, λ—Decay constant of radon (2.098×10^{-6} s^{-1}), T—Counting delay (s), t—Counting duration (s), Θ—Radon build up period (s).

Quality assurance

The accuracy and reliability of the method is verified by analyzing standard reference material, cross method checking, replicate analysis and spike recovery study. Water samples were analysed for total uranium concentration in laser fluorimetry, alpha spectrometry, and mass spectrometry (ICPMS). The results were in good

agreement with each other and the details are given in Table 1. Uranium standard of 5 μg/l is analysed by the above three instrumental techniques in five replicate analysis in order to get the comparison in terms of relative bias and the relative bias associated with the measurement of total uranium by laser fluorimeter, alpha spectrometry and ICPMS were 4, 8 and 14 % respectively. Table 2 depicts the recovery study of ^{209}Po tracer and uranium in certified reference materials. The lower limit of detection (LLD) and the minimum detection activity (MDA) for each method were calculated using either the Currie definition or the formula presented by the Environmnetal Protection Agency (EPA) [44, 45]. The repeatability of all the methods is around 10 %. For ^{210}Po determination, a primary standard solution of activity156.8 ± 1 (±0.8 %) Bq/gm of ^{209}Po solution (Supplied by R33-02 (NPL, National Physical Laboratory, UK) is used for spike recovery study. Secondary standard solution of different activity concentration was prepared by adding appropriate amount of primary standard solution. For determination of uranium in drinking water samples, a certified material (Aldrich) (Atomic Absorption Standard for U determination: activity 1,000 μg/ml) is used for recovery study. The accuracy and precision of the method were evaluated using the supplied certified tracers and standards and the results were in good agreement with the recommended value with a relative error <20 %.

In order to avoid cross contamination, all laboratory glass wares used for sample processing were soaked in 10 % nitric acid for 15 days and then rinsed thoroughly twice with ultra pure water (resistivity 18.1 MΩ, Thermo nanopure diamond TII water purification system) before use.

Table 1 Quality control of uranium analysis

Sl. no.	Uranium conc. (μg/l) by laser fluorimetry	Uranium conc. (μg/l) by α-spectrometry	Uranium conc. (μg/l) by mass spectrometry
1	0.8 ± 0.06	1.0 ± .05	1.4 ± 0.05
2	10.2 ± 1.0	12.6 ± 2.3	8.4 ± 0.3
3	2.5 ± 0.4	2.9 ± 0.9	3.2 ± 0.4
4	10.9 ± 1.1	11.6 ± 1.4	13.3 ± 0.6
5	2.0 ± 0.5	3.8 ± 0.8	4.4 ± 0.5
6	1.8 ± 0.4	2.1 ± 0.4	1.2 ± 0.05
7	13.6 ± 1.5	15.9 ± 2.1	11 ± 0.4

Results and discussion

Distribution of radionuclides

The value pH, TDS and EC of the water which were measured insitu varied in the range of 6.3–8.3, 0.2–4.5 mS/cm and 191–3,570 μg/ml, respectively. The measured activity concentration of total uranium in drinking water samples by laser fluorimetry was varied between <0.2 and 13.6 ± 1.5 μg/l with an average value of 4.3 μg/l. The mean value of specific activity of uranium was 105.6 ± 7.2 mBq/l with a range of <4.9–334.2 mBq/l. The activity concentration of ^{226}Ra, ^{210}Po and ^{210}Pb ranged between <3.5–39.0 ± 3.5, 1.8 ± 0.1–11.0 ± 2.1 and 3.8 ± 0.6–49.7 ± 5.4 with average values of 15.4, 4.8 and 21.3 mBq/l, respectively. The average uranium concentration (105.6 mBq/l) in ground water is much higher than the average ^{226}Ra concentration which can be attributed to high mobility of ^{226}Ra than uranium. The ratio of measured uranium and ^{226}Ra in drinking water samples vary from 0.1–83.7 with a mean value of 8.0. Thus there was a weak

Table 2 Concentration of ^{209}Po tracer and uranium in certified reference material (CRM)

^{209}Po			
Tracer code	Tracer activity added (mBq)	Recovery of ^{209}Po (mBq)	% recovery
Tr-1	199.6	175.0 ± 12.1	87.7
Tr-2	49.9	36.3 ± 5.7	72.8
Tr-3	99.8	87.2 ± 9.3	87.4
Tr-4	149.7	117.2 ± 10.3	78.3
Uranium			
CRM Code	CRM activity added (mBq)	Recovery of uranium (mBq)	% recovery
C-1	50.2	38.6 ± 5.3	76.8
C-2	70.6	60.8 ± 8.5	86.1
C-3	85.2	59.8 ± 7.2	70.0
C-4	100.3	94.2 ± 10.6	94.0

Table 3 Comparison of NORM data from drinking water obtained in the present study with the reported values worldwide

Country	Type of water	Uranium (μg/l)	^{226}Ra (mBq/l)	^{210}Po	^{210}Pb	References
Odisha, India	GW	<0.2–13.6	3.2–39	1.8–11.0	3.8–49.7	Present study
Jaduguda, India	GW	3.6	23.6	–	–	[57]
Jaduguda, India	SW	0.3–54.9	5–283			[57]
Punjab, India	GW	1.4–98.3	–	–	–	[58]
Argentina	–	0.04–11.0	–	–	–	[59]
Bangladesh	SW, GW	–	12–82	–	–	[60]
Brazil	BW	–	647	–	85	[61]
Brazil	GW, SW	–	<2.2–235	–	–	[62]
Finland	GW	–	<10–1,000	–	–	[63]
Finland	GW	24.8	50	50	40	[64]
Hungary	SW	0.1–41.7	2.1–601	2–15.2	–	[65]
Italy	BW	–	<10.0–52.5	<0.04–21.01	–	[66]
Mexico	GW	1.2–54.5	<160	–	–	[67]
Ontario, Canada	–	0.05–4.21	–	–	–	[68]
Poland	GW	–	<10–490	–	–	[69]
Sudan	GW	0.65–70.0	7.7–14.3	–	–	[70]
Turkey	–	0.2–17.6	–	–	–	[71]
Turkey	SW	0.4–10.4	21–1,041	–	–	[72]
WHO, recommended guideline value		30	1,000	100	100	[53]

gw ground water, *sw* surface water, *bw* bottled water

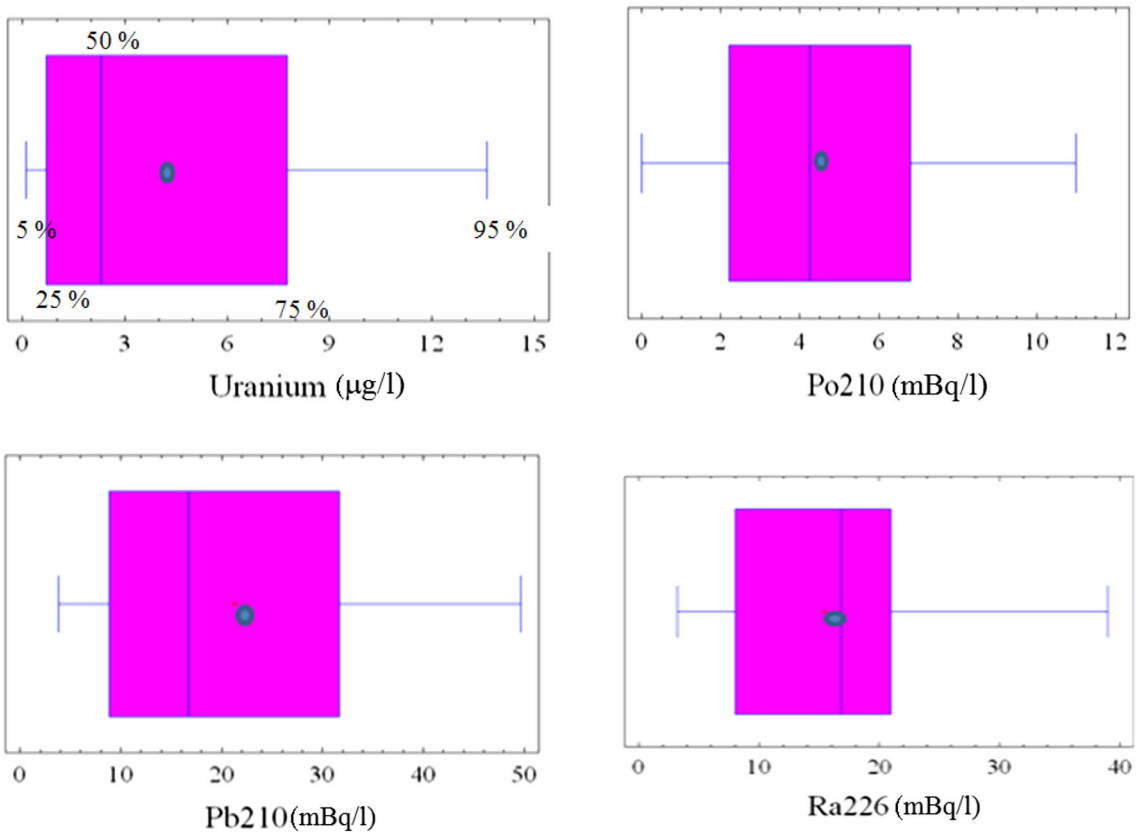


Fig. 2 Box–Whisker plots showing the distribution of NORM in drinking water; the *dot* and *line* in every plot stands for mean and median of the data set respectively

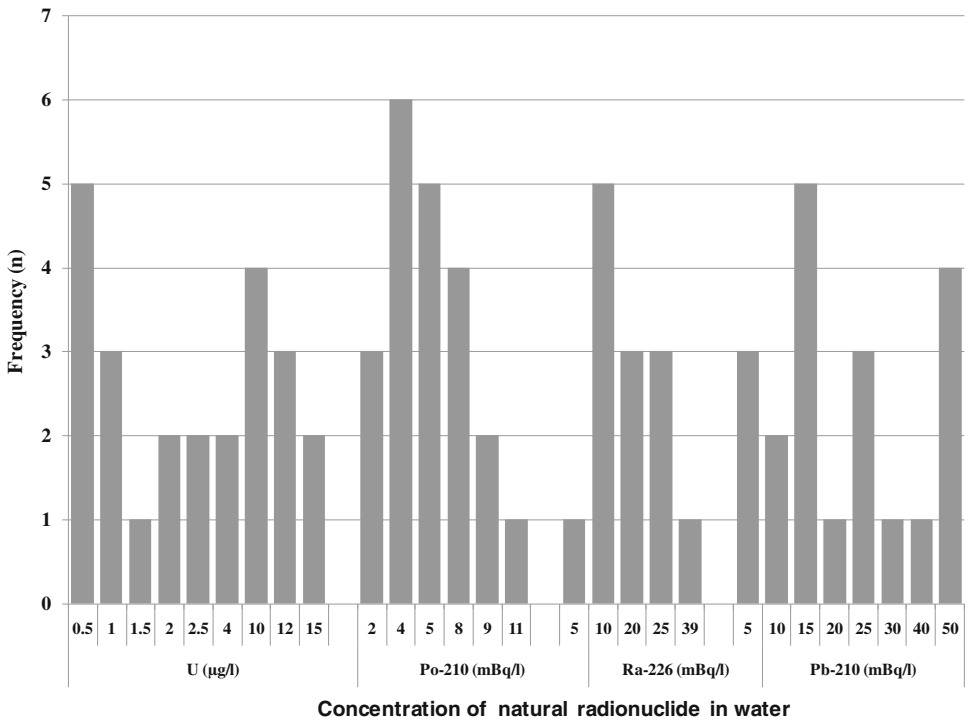


Fig. 3 Histogram plots showing distribution of NORM in drinking water

Table 4 Statistical parameters of NORM data

Statistical parameter	Uranium (µg/l)	^{210}Po (mBq/l)	^{210}Pb (mBq/l)	^{226}Ra (mBq/l)
Mean	4.3	4.8	21.3	15.4
Median	2.3	4.3	16.7	16.8
Standard deviation	4.5	2.7	15.6	9.9
Standard error	0.9	0.6	3.5	2.7
Sample variance	20.3	7.3	242.3	97.6
Minimum	<0.2	1.8	3.8	3.2
Maximum	13.6	11	49.7	39
Skewness	0.9	0.8	0.7	1
Kurtosis	−0.6	−0.3	−0.8	1.3
Mode	0.1	1.8	3.8	17
Geometric mean	1.8	4.1	15.7	12.6
Geometric standard	5.0	1.8	2.3	2.0

correlation (0.13) observed between the concentration of uranium and ^{226}Ra in water samples analysed, which is also an indicator of different geochemical behavior of uranium and radium. The concentration of NORM in drinking water samples were compared to the results obtained from the drinking water samples collected around Jaduguda, India [46]. The concentration of radium in drinking water is comparable in other reported values of Vizag and Odisha, India [47, 48]. The concentration of uranium in drinking water samples was comparable with the reported value of Vizag, India [49], since Vizag, AP, India has the similar mineralization as the study area [50]. The concentration of uranium and radium obtained in the present study is comparable with the similar study in Jaduguda, India [43, 51]. The concentration of radium and uranium obtained in the present study is comparable with the reported values of Syria [51]. The concentration of NORM value obtained from drinking water analysis in the present study is compared with the other reported data worldwide (Table 3). The concentration of uranium in all the drinking water samples was below the guideline value of 30 µg/l [53, 54] and 60 µg/l [55]. The mean activity concentration of ^{226}Ra was 15.4 mBq/l which is much lower than the WHO guideline value of 1 Bq/l [53]. The activity concentration of ^{210}Po and ^{210}Pb were also lower than the WHO guideline value of 100 mBq/l [53].

Distributions of NORM in drinking water are plotted in Box–Whisker and Histogram plot as shown in Figs. 2 and 3 respectively. From the Box plot it is clear that the data doesn't follow normal distribution as mean is not equal to median. The wide variation of data is clear from the Box plot. ^{210}Po data deviates from log normal distribution. The statistical parameter of NORM data is listed in Table 4. Large spreading of the ^{210}Pb data is showing in its large variance value. The NORM data are positively skewed means have distributions with an asymmetric tail extending toward more positive values. Negative kurtosis of the data indicates relatively flat distribution.

The contour map of radionuclide concentration distribution is shown in Fig. 4a–d. Contour map was drawn

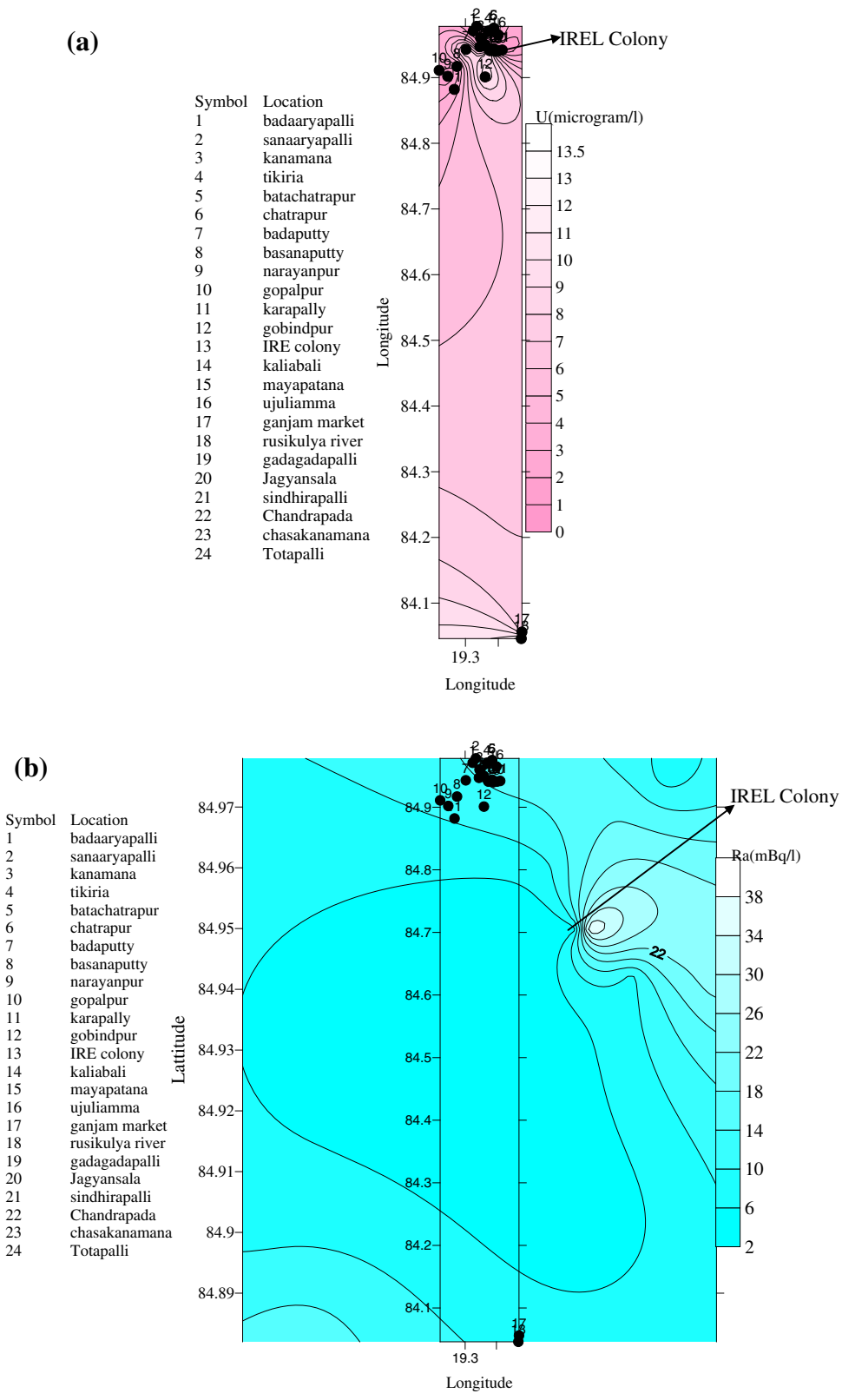
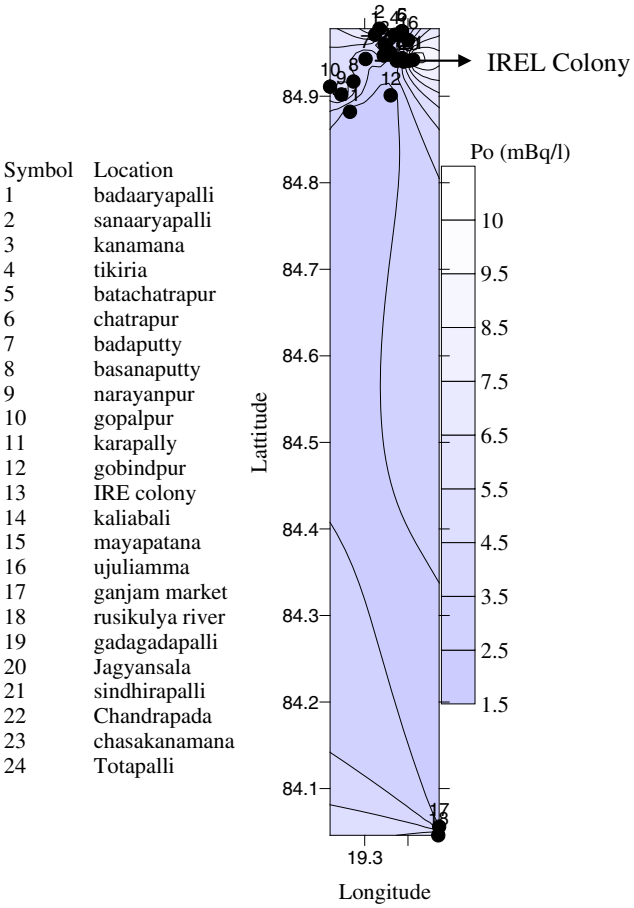


Fig. 4 Contour map of NORM concentration distribution with GPS data

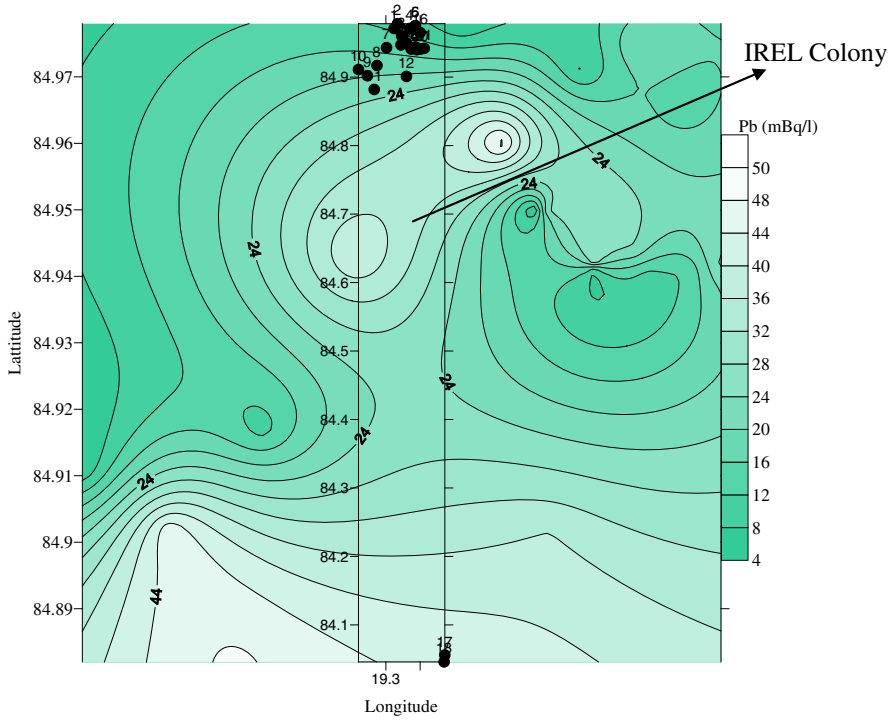
using surfer and the kriging method for griding the data. The IREL industry is located along the coordinates 19.322°N and 84.947°E and indicated in the figure. From the contour maps it is clear that the natural radioactivity in drinking waters from the industrial site was within the prescribed limits and no trend was observed with

(c)



Symbol	Location
1	badaaryapalli
2	sanaaryapalli
3	kanamana
4	tikiria
5	batachatrapur
6	chatrapur
7	badaputty
8	basanaputty
9	narayanpur
10	gopalpur
11	karapally
12	gobindpur
13	IRE colony
14	kaliabali
15	mayapatana
16	ujuliamma
17	ganjam market
18	rusikulya river
19	gadagadapalli
20	Jagyansala
21	sindhirapalli
22	Chandrapada
23	chasakanamana
24	Totapalli

(d)



Symbol	Location
1	badaaryapalli
2	sanaaryapalli
3	kanamana
4	tikiria
5	batachatrapur
6	chatrapur
7	badaputty
8	basanaputty
9	narayanpur
10	gopalpur
11	karapally
12	gobindpur
13	IRE colony
14	kaliabali
15	mayapatana
16	ujuliamma
17	ganjam market
18	rusikulya river
19	gadagadapalli
20	Jagyansala
21	sindhirapalli
22	Chandrapada
23	chasakanamana
24	Totapalli

Fig. 4 continued

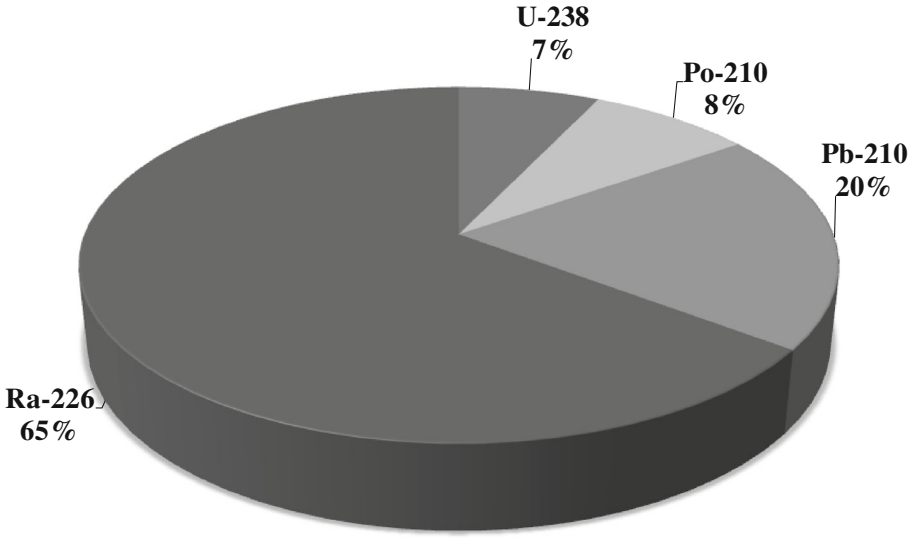


Fig. 5 Contribution of radionuclides to ingestion dose from drinking water

Table 5 Ingestion dose received from radionuclides in drinking water

Radionuclides	Range (μSv/y)	Mean (μSv/y)
^{238}U	0.2–22.2	7.0
^{226}Ra	13.2–161.4	63.9
^{210}Po	2.2–19.5	8.1
^{210}Pb	3.9–50.7	19.7

increasing distance from the IREL site and the distribution was disseminated as evident from the contour plots. The wide variation and some of the higher value may be attributed to the heterogeneous distribution of localized placer deposits of the study area [8, 31, 32].

Effective dose estimation

Effective dose due to drinking water ingestion for adult population (>17 years) can be computed [34] by using the yearly intake of drinking water (4.05 l/d) and IAEA, Basic Safety Series (BSS) dose conversion factors (DCF) for the concerned radionuclides [56].

DCF for ^{238}U, ingestion route $= 4.5 \times 10^{-8}$ Sv/Bq
DCF for ^{226}Ra, ingestion route $= 2.8 \times 10^{-6}$ Sv/Bq
DCF for ^{210}Po, ingestion route $= 1.2 \times 10^{-6}$ Sv/Bq
DCF for ^{210}Pb, for ingestion route $= 6.9 \times 10^{-7}$ Sv/Bq

Mass concentration of natural uranium observed in drinking water can be expressed in activity concentration using a conversion factor of approximately 25 Bq/mg assuming natural uranium composition. Annual committed effective dose can be computed using the formula;

$$\text{Dose}\left(\frac{\mu\text{Sv}}{\text{y}}\right) = \text{Activity conc.}\left(\frac{\text{Bq}}{\text{l}}\right) \times \text{Water intake}\left(\frac{\text{l}}{\text{y}}\right) \times \text{Dose conversion factor}\left(\frac{\text{Sv}}{\text{Bq}}\right) \quad (3)$$

The mean and range of the ingestion dose due to U, ^{226}Ra, ^{210}Po and ^{210}Pb to adult population residing around OSCOM, Odisha from drinking water sources is given in Table 5. The mean value of total effective dose to member of public due to these radioanuclides via drinking water ingestion was found to 67.1 μSv/y with a range of 13.2–198.5 μSv/y. The individual contribution of radioanuclides to the total dose is shown in pie chart (Fig. 5). The main contributor towards the total dose received by the population from drinking water intake is from ^{226}Ra ingestion (65 %). A similar trend was observed in a previous study of the same region [48]. The global annual ingestion dose fall in the range of 200–1,000 μSv/y with a mean of 290 μSv/y [1]. The effective dose received from the present study due to drinking water intake is well within the range of UNSCEAR reported values [1].

Conclusion

A thorough knowledge of the radionuclide concentration in various environmental matrices is imperative in perspective of radiation dose assessment to public. The reason for wide variation of activity concentration in the present study area may be due to heterogeneous distribution of thorium which arises mainly due to monazite placer deposit in the beach sand. The mean value of total effective dose to

member of public due to these alpha emitting radionuclides via drinking water ingestion was found to 67.1 μSv/y with a range of 13.2–198.5μSv/y. considering the spatial distribution of radionuclides, no trend was observed with increasing distance from the IREL site and the distribution was disseminated. From the present study it can be concluded that the drinking water which is mostly the ground water (tube well) is not affected by the beach sand mining industry and the activity concentration is due to natural distribution of radioanuclides which is safe for human consumption considering the NORM present therein.

Acknowledgments Authors gratefully acknowledge the guidance and encouragement of Dr. D. N. Sharma, Director, Health Safety and Environment Group, BARC. The help and support received from the colleagues of Health Physics Units, Orissa Sands Complex, and the authorities of IREL during environmental sampling and survey of the study area is greatly acknowledged by the authors. The whole heartedly contribution of Dr. Manoj Mohapatra, Radiochemistry Division, BARC is greatly acknowledged during sampling and survey of the study area. Authors are truly grateful for the cooperation received from other colleagues of the lab during the progress of this work.

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