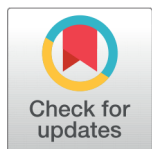


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# Scenario of radon alpha activity level in natural drinking waters of different regions of eastern part of India: A review report

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## Abstract

**Background/Objectives:** High density to alpha-particle radiations, particularly from radon, can increase health risks. This study presents the radon alpha-activity of drinking waters in regions of eastern part of India. **Methods/Statistical analysis:** To figure out radon alpha-activity concentration in natural drinking waters in the above mentioned regions, present study reviewed many literatures that pertinent to radon alpha-activity of waters in the regions. Both inclusion and exclusion criteria have been followed to select the literatures for review. This study consulted the reports of literatures for obtaining data sources. Recommendations of national and international groups have been used to interpret the results. **Findings:** A wide variation of radon alpha-activity concentration in drinking water of the regions has been found in between 0.31 and 911 Bq/l. Most of the radioactivity values exceeded MCL or reference level recommended by USEPA and UNSCEAR, and few are exceeding action limit given by EU and WHO. High alpha-activity level in waters has been seen in the arsenic and fluoride contaminated areas and near the areas of U-mine and thermal springs. Low level of alpha-activity has been seen in some regions of Assam, Meghalaya, Mizoram and Orissa, and in the east coast region of West Bengal. The radon alpha-activity level in coastal area of Orissa is higher than that of West Bengal. It is found that the sources of the alpha-emitting radionuclides, arsenic and fluoride may coexist in the arsenic and fluoride contaminated regions. This study is the first that reviewed the alpha contamination level in natural drinking waters in the eastern part of India. More studies on these regions are required in the future. **Novelty/Applications:** Novelty of this study relies on the observed alpha-activity of drinking waters in the regions. Radioactivity data provided in this study can help to researchers for further investigation.

**Keywords:** Natural waters; Alpha emitters; Radon; Alpha activity; Human health; India

## 1 Introduction

Water is indispensable for human life. Its pure form is available in our earth's ground. Groundwater is mainly used as drinking water, and occasionally it is used in other purposes. Purity of natural drinking water is sometimes disturbed by the presence of various non-essential elements, and one of these elements is radionuclide (radioactive element).

The radionuclides present in drinking water are generally natural, resulting from dissolution of both gases and rock minerals, or even they may be produced artificially, from the results of different human activities<sup>(1)</sup>. Most of the radionuclides in drinking-water are likely to be from natural sources such as rock types than artificial or man-made sources such as nuclear power industry. The naturally occurring primordial radionuclides of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{235}\text{U}$  decay series are normally present with varying concentrations in natural drinking waters. But, the availability of radionuclides of  $^{235}\text{U}$  decay series in drinking water is thought to be very poor, because relative abundance of  $^{235}\text{U}$  in nature is only 0.7205% on the average<sup>(2)</sup>. The radionuclides of  $^{238}\text{U}$  and  $^{232}\text{Th}$  decay series in natural drinking-water sources are widely distributed throughout the earth, and their activity concentrations are mainly connected to the activity concentrations of these radionuclides present in the earth's ground and bedrocks through which the raw water may have passed. The higher activity levels of naturally occurring radionuclides are usually found in the drinking waters from different groundwater sources such as from wells and tube-wells than in the surface water such as streams, lakes and ponds. However, in a radioactivity-prone area, the radionuclides can accumulate to harmful levels in natural drinking water. It is observed that the drinking of mineral water rich in primordial radionuclides is a cause of prolonged exposures of human from internal radiation, and the activity concentrations of these radionuclides in potable water may deliver doses up to a few *millisieverts per year*<sup>(3)</sup>. So, the harmful health effects may be induced due to the presence of large amounts of radionuclides in drinking water. The organ that is most likely to be effected on over exposure by a highly radioactive source on whole body is the bone marrow and the process of hematopoiesis<sup>(4)</sup>.

The health effects caused by the radioactivity contaminated drinking-water are mainly associated to the alpha-radiations (high-LET) emitted from the alpha-emitting radionuclides that present in such water. Because, the alpha-particles emitting radionuclides contribute significantly to the radiation doses that people receive<sup>(5)</sup>. Additionally, the alpha-particles have high ability of linear energy transfer (LET) within the exposed living tissues than other penetrating radiations<sup>(6)</sup>. When the alpha particles traversed in the cells, a single alpha particle can deliver energy of about 20 *rad* to a 12  $\mu\text{m}$ -diameter cell<sup>(7)</sup>. The passage of a single alpha particle has the potential to cause irreparable damage in the cells which lead to develop some chronic diseases and cancer in the damaged portions<sup>(8)</sup>. It has been reported in a study that a prolonged exposure of alpha-particle radiations to an organ may lead to increase relative biologic effect on DNA, causing fractures and translocations of the chromosomes<sup>(9)</sup> and finally damaging the chromosomes. Even for a same amount of absorbed dose, the densely alpha-particles radiation is much more effective than the sparsely radiations (low-LET) of gamma rays, X-rays and beta particles, in causing the biological effects (particularly, stochastic effects) and cellular effects such as chromosome aberrations and mutations<sup>(10–12)</sup> as well as in inducing the genomic instability in haematopoietic cells<sup>(12)</sup>.

Among the alpha-emitting radionuclides of natural sources, the radionuclides such as U, Th,  $^{226}\text{Ra}$ ,  $^{210}\text{Po}$ ,  $^{220}\text{Rn}$ ,  $^{222}\text{Rn}$  and the daughters of  $^{228}\text{Ra}$ , all are present in water with varying amounts<sup>(13)</sup>. Most harmful alpha-emitter is the isotope of radon, particularly  $^{222}\text{Rn}$ <sup>(14)</sup>. The radon is the only radioactive gas. It constitutes the most important component of the natural background radiation dose to the population<sup>(15)</sup> and it is estimated that radon contributes 55% of the total ionizing radiation exposure to the public<sup>(16)</sup>. The radon in water is also the main source of the radiation doses for stomach (ingestion dose) and lungs (inhalation dose)<sup>(17)</sup>. Recently, a study found the many health effects induced by exposure to radon in air and water<sup>(18)</sup>. The US-EPA (United States Environmental Protection Agency) estimated from the NAS (National Academy of Science) report that about 11% of the stomach cancer risk caused by drinking water with high concentration of radon and about 89% of the lung cancer caused by breathing radon that released to the indoor air from water with high concentration of radon<sup>(19)</sup>. Higher levels of radon are normally found in the underground rocks rich in uranium, and hence when groundwater infiltrates through the rocks containing uranium it is expected to have high level of radon in groundwater<sup>(20)</sup>. The radiation dose from the radon dissolved in drinking water is depending upon the activity concentration of radon in this water, and that from the indoor radon released from radon-containing groundwater supplies is depending markedly upon the forms of domestic usage and housing construction<sup>(21)</sup>. However, the activity concentration of  $^{222}\text{Rn}$  is generally 37 *mBq/l* in surface water while that is typically a few 1000 times more present in groundwater, and some mineral or spa waters may have 18.5 *kBq/l* of radon activity level<sup>(13)</sup>. Therefore, a wide variation of the radon alpha-activity concentration has been found to be present in natural drinking water from different sources, and their presence in drinking water can result in inducing many health hazard problems in the human body. So, knowing to the radon alpha-activity level in drinking water from different natural water sources of different regions is important in order to assess the quality of drinking water and safety of consumer's health from the radiological protection point of view.

Present study has reviewed some research studies that investigated the level of radon alpha-activity in natural drinking waters from different water sources in different regions of eastern part of India. In the regions of eastern part of India, almost all the rural and urban population intake groundwater as drinking water and used it also in other purposes. The eastern part of India consists of two parts — east India and north-east India. The present review study summarizes the possible sources of alpha-radioactivity contamination in drinking water and the association of radioactivity sources with other elements in the drinking water of the regions.

## 2 Study area

The study area is consisting two regions of eastern part of India — east India and north-east India. The states of eastern part of India are shown in Figure 1. A short description of the study area is given below.

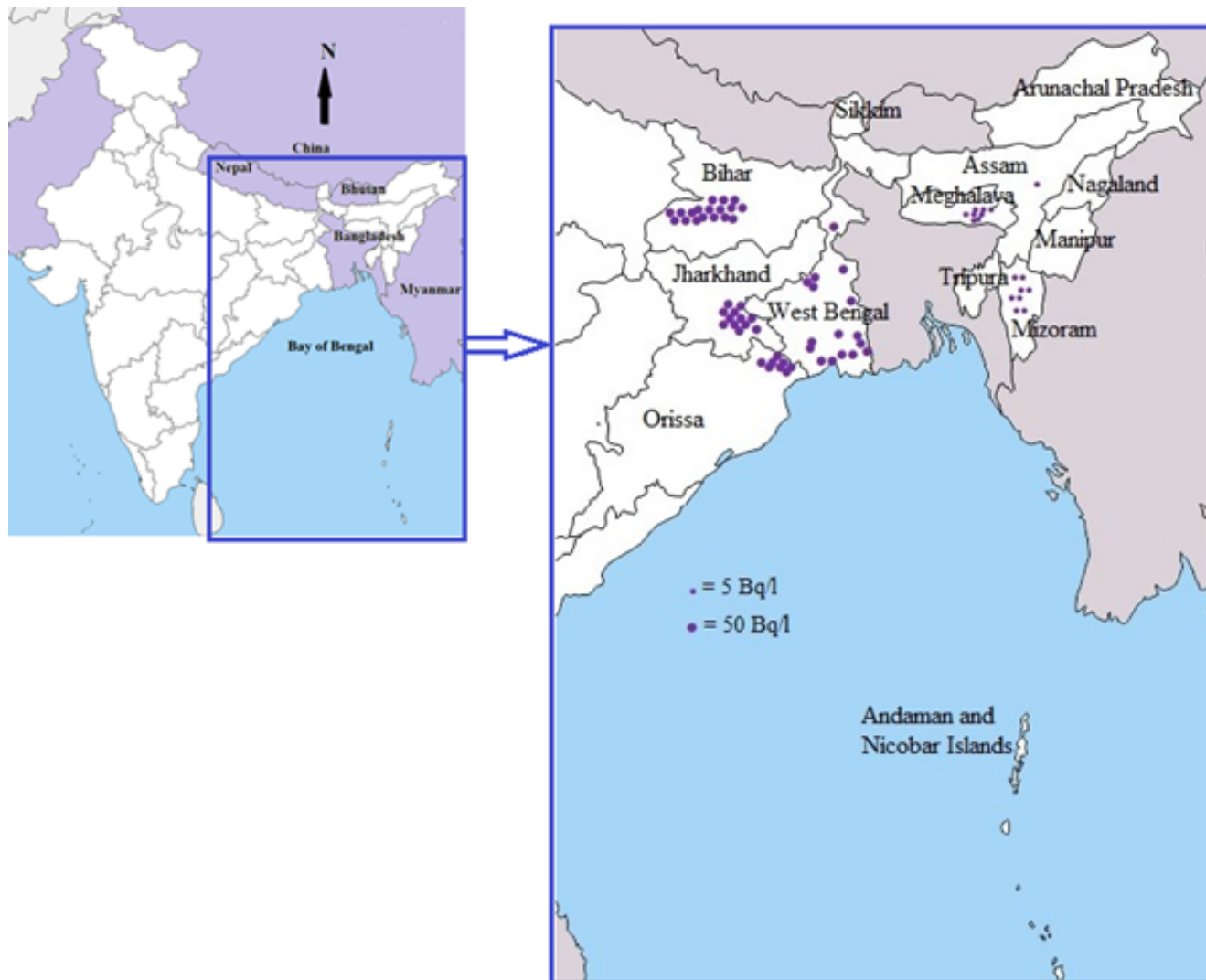


Fig 1. Distribution map of the alpha radioactivity of waters

### 2.1 East India

The east India consists of four states of Bihar, Jharkhand, Odisha (Orissa) and West Bengal, as well as of the union territory of Andaman and Nicobar Islands<sup>(22)</sup>. The northern part of the regions of east India is bounded by two countries of Bhutan and

Nepal and by a state of Sikkim, whereas its southern part is bounded by the state of Andhra Pradesh. The states of Uttar Pradesh and Chhattisgarh lie on the western part of this region, and the country of Bangladesh lies in its eastern part. The region is also bounded by the Bay of Bengal in the south-eastern part. In east India, the Bihar and West Bengal states lie on the Indo-Gangetic plain. The state Jharkhand lies on the Chota Nagpur Plateau. The Odisha state is situated on the Eastern Ghats and the Deccan Plateau. The union territory of Andaman and Nicobar Islands is lying on the Bay of Bengal. The region of east India has the humid-subtropical climate. Summer of the region is from March to June, and mild winters from November to February. The July to October is the monsoon period. The region has a drier climate and slightly more extreme climate, particularly in the winter and summer seasons. The whole region receives heavy and sustained rainfall during monsoon period.

## 2.2 North-east India

The north-east India comprises eight states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura<sup>(23)</sup>. The region is bounded by the countries of China in the north, Myanmar in the east, Bangladesh in the south-west, Nepal in the west, and Bhutan in the north-west. The West Bengal state is situated in the western part of this region. Physiographically, the regions of north-east India can be categorised into Eastern Himalaya, Patkai, and the Brahmaputra, Barak and Imphal valley plains. The region has some flatlands in between the hills of Meghalaya and Tripura. The region of north-east India has a predominantly humid sub-tropical climate with hot, humid summers, severe monsoons, and mild winters. The region has the sources of petroleum and natural gas. The Himalayas to the north, the Meghalaya plateau to the south and the hills of Nagaland, Mizoram and Manipur to the east influences the subtropical climate.

The rainy season coincides with the summer months much like the rest of India. Winter is from early November to mid-March while summer is from mid-April to mid-October. April to late October are the months where most of the rainfall in Northeast India occurs with June and July being the rainiest months. The high rainfall (averaging around 10,000 mm and above) of this region creates problems of the ecosystem, high seismic activity, and floods. The region of north-east India is the rainiest region in India, with many places receiving an average annual precipitation of 2,000 mm. Cherrapunji located on the Meghalaya plateau is one of the rainiest place in the world with an annual precipitation of 11,777 mm. Temperatures are moderate in the Brahmaputra and Barak valley river plains which decrease with altitude in the hilly areas. Temperatures vary by altitude with the warmest places being in the Brahmaputra and Barak River plains and the coldest at the highest altitudes. Generally, temperatures in the hilly and mountainous areas are lower than the plains which lie at a lower altitude.

The north-east region of India is a mega-earthquake prone zone caused by active fault planes beneath formed by the convergence of three tectonic plates viz. India Plate, Eurasian Plate and Burma Plate.

## 3 Reason for selecting the regions of eastern part of India

The eastern part of India has been chosen in the present study, because, in the regions of eastern part of India there are present some geothermal hot-water springs, radioactive minerals, mountains and mines – these are normally rich with different amounts of naturally occurring radioactive elements along with some non-radioactive elements. The geothermal springs or hot-water springs are present in the states of West Bengal, Sikkim, Arunachal Pradesh, Assam, Meghalaya, Odisha, Bihar and Jharkhand, and in the Andaman and Nicobar Islands of the eastern part of India (<https://geographyandyou.com/hot-water-springs-in-india/>)<sup>(21)</sup>. Various research studies determined the radioactivity levels in spring waters in different region of eastern part of India<sup>(24–26)</sup>. A study reported that the presence of helium in thermal springs of Odisha state is possibly due to disintegration of radioactive elements in Pre-cambrian terrain<sup>(27)</sup>. Some studies reported the presence of significant amounts of U and Th bearing minerals such as monazite and zircon sands in the eastern and southern coastal parts of Orissa state<sup>(28,29)</sup>. The granite gneiss, the most common rock and consists of many minerals, has been present in the district of Dhanbad of Jharkhand state. In Dhanbad district, the largest producer of coal mines among all Indian states is present there. A study reported that the mean activity concentrations of <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K radionuclides in sandy-loamy soils from the coal mines at Sijua near the Dhanbad city of Jharkhand have been present above the world values<sup>(30)</sup>. Among the two functional uranium mines in India, one is located at Jaduguda in East Singhbhum district of Jharkhand state. Elevated levels of uranium and <sup>226</sup>Ra in the untreated effluent water from Jaduguda uranium mines, mill tailings ponds and effluent treatment plant have been reported in a study<sup>(31)</sup>. The presence of the highest levels of concentrations of <sup>238</sup>U and <sup>232</sup>Th radionuclides have been seen in the soils from Kylleng-Pyndensohiong (Mawthabab) areas of the district of West Khasi Hills of Meghalaya state<sup>(32)</sup>. According to the report of the Department of Atomic Energy (DAE), the significant uranium anomalies are located in Arunachal Pradesh state, the uranium oxide ( $U_2O_8$ ) has been reserved in the areas of the states of Jharkhand and Meghalaya, and the significant zone of total heavy mineral (THM) concentration have been located at Odisha state. In addition to this, the significant uranium mineralized intercepts/bands have been identified in boreholes drilled at Jharkhand state<sup>(33)</sup>.

From the above mentioned reports, it is evident that in the regions of eastern part of India there are present a number of radioactive sources, and hence there is a chance of getting radioactive contamination in the natural drinking waters. Many studies reviewed the present of different kind of heavy elements, other than radionuclides, in the eastern part of India (34–41). But, not a single study has been found that has aimed to review the radon activity concentration in natural drinking waters in the regions of eastern part of India. For this, the present review study emphasized to figure out the present scenario of the radon alpha-activity level in natural drinking waters from different parts of this region. This study care about alpha activity of water, because presence of alpha-emitters, particularly radon, in water can results in inducing many health hazard problems including malignant diseases and hereditary effects in the human body.

#### 4 Materials and methods

The present study has overviewed numerous published research studies that reported the radon alpha activity levels in natural drinking waters from different regions in eastern part of India. To identify such relevant studies, various search terms or key words such as the sources of radionuclides in natural waters, the natural radioactivity, alpha activity and radon-alpha activity of drinking water, the entry of alpha emitters in water and human body, the regions of eastern part of India, and also the health effects associated to the alpha-particle emitters, have been used in searching process. A few relevant reference lists from the original published studies are also used to identify the additional relevant publications (18). During the searching, firstly screened all the titles and abstracts of all the studies, and then read the abstract and full text. After screening process, the present review study has determined the aims and purposes of these published studies or literatures. The present study has selected a number of published research articles, review reports, including PubMed database and books, which are pertinent to the present study. All these literatures have been written and published in English language in different national and international reputed journals and books. The period of coverage of all the literatures included in the present study is in between 1977 and February, 2021.

The studies that investigated the concentrations of non-radioactive elements (with few exceptions) in natural drinking water have been excluded from review, whereas that investigated the level of radon alpha-activity in natural water have been included for the review. Since, the studies that have included for the review meet the eligibility criteria or requirements for the present study, the required data or information regarding the radon alpha-activity from each of these studies are then extracted and used finally in respective sections of the present study. For obtaining the data sources, the present study consulted the literatures that reported the radon alpha activity of natural water in the eastern part of India.

The radioactivity results obtained from all the published studies for different states of eastern part of India have been presented in Table 1. The radioactivity data provided in these studies have been interpreted and discussed clearly in the respective sections of the present study. Table 2 has been presented for tabulating the range and cause of radon alpha-activities.

**Table 1.** Scenario of alpha activity level in natural drinking water

State	Location in state	Sources of drinking water	Alpha activity (Bq/l)		References
			Range	Average	
Assam	Different places, Karbi Anglong district	Surface and ground waters	0.46 ± 0.03 to 5.00 ± 0.33	-	[Kakati and Bhat-tacharjee, 2011]- (42)
Bihar	Arsenic prone areas, of Bhojpur, Buxar, Baishali and Patna districts	Tube-well	68 to 911	-	[Ghosh et al., 2008]- (43)
Jharkhand	Along Subarnarekha River, East Singbhum district	Tube-well	482 to 590	536	[Ghosh et al., 2010]- (44)
	Around Jaduguda U-mine, East Singbhum district	Groundwater	7.5 to 389.6	123.5	[Sethy et al., 2015]- (45)
Meghalaya	Different areas of Shillong agglomeration, East Khasi Hills district	Groundwater	8.60 to 39.55	-	[Walia et al., 2011]- (46)
Mizoram	Some regions, Aizawl and Kolasib districts	Stream water, spring water, pump water, open well, pond and supply water	0.309 (supply water) to 32.53 (bore-well water)	6.88	[Hmingchungnunga et al., 2018]- (25)
	Some regions, Champhai and Serchhip districts	Streams, springs, pumps, open well and supply water	0.40 (surface water) to 41.68 (surface water)	-	[Hmingchungnunga et al., 2020]- (26)
Orissa	Along Subarnarekha River, Mayurbhanj district	Tube-well	332 to 386	359	[Ghosh et al., 2010]- (44)

*Continued on next page*

Table 1 continued

	Coastal area in Baleshwar district	Groundwater	1.6 ± 0.21 to 17.0 ± 1.69	8.98 ± 0.85	[Krishan et al., 2014]. <sup>(47)</sup>
West Bengal	Arsenic prone areas of North 24 Parganas and South 24 Parganas districts	Tube-well	39 to 220	-	[Ghosh et al., 2004]. <sup>(48)</sup>
	Arsenic prone areas of South 24 Parganas, North 24 Parganas, Nadia, Murshidabad, Malda and Kolkata districts	Tube-well	8 to 800	-	[Ghosh et al., 2008]. <sup>(43)</sup>
	Along Subarnarekha River, Paschim Medinipur district	Tube-well	336 to 472	418	[Ghosh et al., 2010]. <sup>(44)</sup>
	Thermal springs at Bakreswar, Birbhum district	Water and bubbling gas of different springs	3.18 ± 1 to 46.9 ± 5	-	[Chaudhuri et al., 2010]. <sup>(24)</sup>
	East coast region	Groundwater	1.9 ± 0.78 to 9.0 ± 1.13	5.0 ± 0.83	[Krishan et al., 2015]. <sup>(49)</sup>
	South 24 Parganas, and East Medinipur districts at East coast region	Hand-pump	1.9 to 9.0	4.98	[Krishan et al., 2015]. <sup>(50)</sup>
	Bakreswar geothermal area, Birbhum district	Tube-well	3.3 to 355.2	83.2	[Naskar et al., 2017]. <sup>(51)</sup>

Table 2. Range, minimum and maximum alpha activity values in natural drinking water

State	Range of alpha activity (Bq/l)	Minimum radioactivity found in	Maximum radioactivity found in	Remarks for high alpha radioactivity of water
Assam	0.46 to 5.00	Supply water	P.H.E. water	High alpha radioactivity found in water of very high fluoride contaminated areas.
Bihar	68 to 911	Groundwater	Groundwater	High alpha activity occurred in some areas where the arsenic contamination in groundwater is much higher than the maximum permissible limit of 50 ppb .
Jharkhand	7.5 to 590	Groundwater	Tube-well water	High level of radioactivity in groundwater may be due to the leaching of uranium from uranium mine, uranium mineralization of mine, and also local geological features of the area.
Meghalaya	8.60 to 39.55	Groundwater	Groundwater	Levels of alpha radioactivity in water vary with seismic activity in the region.
Mizoram	0.309 to 41.68	Supplied water	Surface water	The alpha activity concentration in water has been found to be highest during summer followed by monsoon and lowest in winter.
Orissa (Odisha)	1.6 to 386	Groundwater	Tube-well water	High level of radioactivity in groundwater may be due to the leaching of uranium from uranium mine, and local geology.
West Bengal	1.9 to 800	Groundwater	Tube-well water	High alpha radioactivity found in arsenic contaminated water, spring water, and water contaminated by the effect of uranium mine.

A number of national and international groups in the world have periodically studied the sources and levels of the alpha-particles radiation in water. These groups have also estimated the corresponding health effects to man and provided valuable recommendations based on the assessments of radiation hazards. Among these, whose reports and recommendations have been used in different sections in the present study are the National Academy of Sciences (NAS) Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR), United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), International Commission on Radiological Protection (ICRP), National Council on Radiation Protection and Measurements (NCRP), Bhabha Atomic Research Centre (BARC), Department of Atomic Energy (DAE), Indian Society for Radiation Physics (ISRP), European Union (EU) Commission, and also the World Health Organization (WHO). Results of the present study have been interpreted by consulting the reports and recommendations of these groups and some research studies.

Some of the above mentioned groups have been set the permissible levels of alpha exposure from some alpha-emitters in water. As per the safe drinking water act direction, the USEPA proposed MCL of 11.1 Bq/l for radon in drinking water<sup>(52)</sup>. The EU recommends the reference level of 100 Bq/l of radon activity level in water for public drinking water supplies<sup>(53)</sup>. The action level of radon in drinking water is 100 Bq/l recommended by WHO<sup>(54)</sup>. The UNSCEAR suggests a range of 4 – 40 Bq/l of radon activity levels in water for human consumption<sup>(55)</sup>.

## 5 Result and discussion on the reported radon alpha activity levels in drinking waters of eastern part of India

The levels of radon alpha-activity concentration in natural drinking waters from different natural sources located at different regions of some states in the eastern part of India have been reported in many research studies. The main findings of these studies are described separately for different states as follows:

### 5.1 Assam

In Assam state, only a study has been found that estimated the total alpha activity in various sources of 10 drinking water samples in 10 different places of Karbi Anglong district<sup>(42)</sup>. The selected sources of drinking water samples contain high fluoride concentrations. In the measurement technique, they have used LR-115 (Type-II) solid state nuclear track detectors (SSNTDs). Detectors were kept at the center of the water filled plastic container of volume 416 cm<sup>3</sup>. Exposure of LR-115 to alpha-radiations was done for 72 h. The minimum and maximum values of alpha activity of 0.46 ± 0.03 Bq/l and 5.00 ± 0.33 Bq/l have been reported respectively for water supply (at Diphu Town) and Kheroni P.H.E. water (at Kheroni) of the district. Results of this study indicate all the alpha activity values are below the maximum contaminant level (MCL) of 11.1 Bq/l as set by USEPA<sup>(19)</sup>. Authors have seen that the alpha-particle track density registered on LR-115 detectors is relatively much higher for the water samples of very high fluoride concentrations areas of Longnit Bura Teron Gaon and Kheroni of the district. This observation indicates the high fluoride contaminated waters contain high alpha activity or high concentrations of alpha-emitters. Authors have suggests the high concentration of registered alpha tracks needs further investigation for any conclusion. In this study, however, it is not explain about the association between high alpha-activity level and high fluoride concentration in water from the fluoride contaminated areas. But, recently some studies have found a statistically significant positive correlation between radon concentration and fluoride content in groundwater of different regions of Karnataka state of India<sup>(56,57)</sup>. So, the sources of high concentrations of alpha-emitting radionuclides and fluoride may coexist in the fluoride contaminated area of this district.

From this study, it is found that the alpha activity of water ranges from 0.46 ± 0.03 Bq/l to 5.00 ± 0.33 Bq/l in this district of the state of Assam.

### 5.2 Bihar

In Bihar state, only a study has been found that investigated the alpha activity level in 50 samples of drinking water from 15 blocks in Bhojpur, Buxar, Baishali (Vaishali) and Patna districts where arsenic contamination is severely affected and population density is relatively high<sup>(43)</sup>. The alpha activity measurement has been performed in this study by using CR-39 SSNTDs. The SSNTDs have been hanged from a glass rod stand, and the glass rod has been dipped into the water sample kept in a beaker. Exposure to alpha-particle radiations has been continued for 45 h. The measured alpha activity values have been present in between 68 and 911 Bq/l. This study observed that all the alpha activity values are much higher than the MCL of 11 Bq/l set by US-EPA<sup>(58)</sup> and also much higher than the world average value of 10 Bq/l given by UNSCEAR<sup>(10)</sup> and WHO<sup>(59)</sup>. The minimum and maximum values of the alpha activity are respectively found to be around 6.1 and 82.1 times the MCL value. The alpha activity of about 80% samples examined in this study is exceeding the threshold limit for radon activity level of 100 Bq/l in drinking water<sup>(54)</sup>, and these samples show their alpha activity 1 to 10 times this action level. Results of this study indicate the presence of high alpha activity in all the water samples. Authors have noted that the high alpha activity has been present in some areas where the arsenic contamination in groundwater is much higher than the maximum permissible limit of 50 ppb, although few exceptions have also been noted by the authors. Investigation of this study revealed that the severely arsenic contaminated drinking waters are highly alpha active, and the alpha activity level is positively correlated with arsenic level in this area. So, the coexistence of both arsenic and radioactive sources has been present in the areas of these four districts.

Based on the data mentioned in this study, it is observed that the alpha activity of groundwater of these four districts in this state is ranging in between 68 and 911 Bq/l.

### 5.3 Jharkhand

A study investigated the effect of radioactive contamination on the waters of Subarnarekha River and tube-wells near and far sites of the Jaduguda uranium (U) mine in East Singhbhum district of Jharkhand state<sup>(44)</sup>. This study found the high levels of alpha activities in the waters from river and tube-wells along the path of the river near the U-mine area. The authors have used CR-39 track detectors for estimating the alpha activity of the water samples. The SSNTDs have been attached with a glass rod stand that has been dipped into the water sample taken in a beaker. Exposure of CR-39 plates to alpha-particle radiations has been continued for 48 h. The alpha activity level in the tube-well water samples of two locations of East Singhbhum district has been found to be present in between 482 (at Ghatsila) and 590 Bq/l (at Jamsola). The authors have observed that this range of alpha activity values exceeds the USEPA's recommended MCL value of 11 Bq/l, and that also exceeds the world average value of 10 Bq/l given by UNSCEAR<sup>(10)</sup> and WHO<sup>(59)</sup>. It is observed that the alpha activity values in tube-well waters reported in this study are around 43.4 to 53.2 times the MCL value recommended by USEPA and that are also around 4.8 to 5.9 times the action level recommended by WHO<sup>(54)</sup>. The study reported that the water system has been severely alpha contaminated near or even far sites of the mine area. This is because of the leaching of uranium in huge amount near the mine area, and thereby enhanced the alpha activity level in the tube-well waters in the area.

Measurement of waterborne radon level in 30 groundwater samples from 30 different locations around uranium mineralization area of Jaduguda in East Singhbhum district has been performed by Sethy et al.<sup>(45)</sup>. In this study, they have used the Alpha-Guard device for measuring the radon dissolved in the water samples. The water sample of 100 ml has been transferred to the sample container of the device. The Alpha-Guard has been kept in the flow mode. The alpha pump has been operated at 0.5 lpm for 30 min. The water sample starts bubbling which emanates radon that dissolved in water sample and allows it to flow to the ionization chamber region of the device. Then the radon concentration in the sample has been measured by using a suitable equation mentioned in this study. The authors have found a wide variation of radon activity concentration in water from the Singhbhum shear zone. This variation is in between 7.5 and 389.6 Bq/l with a mean value of 123.5 Bq/l. The minimum and maximum values of radon level in the water samples have been present at Chatikocha village and Kalimandir Station Road, respectively. It has also been observed by authors that almost all the water samples have radon alpha activity level above the USEPA's recommended MCL value of 11.1 Bq/l, and more than 50% of the samples show their alpha activity levels above the European Union (EU) Commission's recommended reference radon level of 100 Bq/l in drinking water. It is found in this study that the radon alpha activity levels above the USEPA's recommended MCL are about 0.7 to 35.1 times the MCL value. Also, more than 50% of the estimated radon activities are around 1 to 3.9 times the WHO's recommended action level of 100 Bq/l<sup>(54)</sup>. It has been noted in this study that the variation of radon alpha activity level in water is associated to physical properties of aquifer material and that is also varying with the concentration of uranium in solid phase in the locations. Additionally, the elevated level of radon activities in some groundwater samples may attribute to uranium mineralization and local geological features of the area. This study has not seen a significant correlation between radon and radium in groundwater ( $R^2 = 0.089$ ).

However, from these two studies, it is found that the radon alpha activity of water ranges from 7.5 to 590 Bq/l in the region of this district, and most of the drinking waters have radon alpha activity level above the 100 Bq/l.

### 5.4 Meghalaya

In Meghalaya state, only a study<sup>(46)</sup> investigated the radon activity level in some potable groundwater samples from 19 sites located in different areas of Shillong agglomeration of the district of East Khasi Hills. The water samples have been collected in 1 l air-tight water bottle on fortnightly basis for 6 months. The Alpha-Guard device has been operated at 1 min flow mode for radon level measurements after background assessment. The measured radon activity level in the water samples varies from 8.60 to 39.55 Bq/l, and its maximum value is above the US-EPA's recommended MCL of 11.1 Bq/l<sup>(19)</sup>. The minimum and maximum values of the radon levels in the samples examined in this study are respectively around 0.8 and 3.6 times the USEPA's recommended MCL value of 11.1 Bq/l. All the radon activity values are far below the WHO recommended action level of 100 Bq/l of radon in drinking water<sup>(54)</sup>. The authors observed that the radon levels in water samples vary with seismic activity in the region, and direct correlation has also been noticed by the authors.

From this study it is seen that the radon alpha activity level in natural water of this district has been ranged in between 8.60 and 39.55 Bq/l

### 5.5 Mizoram

Assessment of radon content in 64 water samples from different water sources in two districts of Aizawl and Kolasib of the state of Mizoram has been conducted in a study<sup>(25)</sup>. The water samples examined in this study have been collected from stream



water, spring water, pump water, open well, pond and from government supplied water. Measurement of radon content in the water samples has been performed using SMART RnDuo monitor. The radon gas in the setup has been flushed for 5 min by using an inbuilt pump to eliminate background. In this measurement process, this monitor is connected with bubbler attached to the sampling bottle using flexible tubing. The pump is running for 3 min so that the dissolve radon in water can escape into the tubing. Measurement has been taken in 15 min – cycle for 1 h. The measured radon activity concentration in waters from Aizawl district is in between 0.309 Bq/l (supplied water) and 32.53 Bq/l (bore-well water) with an average value of 7.33 Bq/l, whereas for Kolasib district the radon concentration in waters is varying from 1.11 Bq/l (spring water) to 22.17 Bq/l (spring water) with an average of 6.31 Bq/l. The overall average content of radon in water has been found as 6.88 Bq/l, which is below the US-EPA's recommended MCL value of 11.1 Bq/l<sup>(19)</sup>. It has been reported in this study that the measured radon content in waters from most of the water sources is well within the MCL value, except for few samples analysed. It is seen that the highest level of radon activity concentration has been present in the bore-well water of Aizawl district and in the spring water of Kolasib district. Maximum radon activity concentration in the water samples of Aizawl district has been found to be 2.93 times the USEPA's recommended MCL value, while that has been found to be about 2 times the MCL value for the water samples of Kolasib district. So, relatively highest value of radon level has been present in Aizawl district. It is observed that about 16.67% water samples of Aizawl district and about 14.29% water samples of Kolasib district show their radon activity values above the US-EPA's recommended MCL of 11.1 Bq/l, however, all the measured radon activity values are far below the WHO recommended action level of 100 Bq/l of radon in drinking water<sup>(54)</sup>.

Seasonal variation of the concentration of radon in 49 different water samples from streams, springs, pumps, open well and from government supplied water of different locations of two districts of Champhai and Serchhip of Mizoram has been investigated by Hmingchungnunga and team<sup>(26)</sup>. Radon content in the water samples has been estimated by using SMART RnDuo portable radon monitor. To eliminate any background, the radon gas in the setup has been flushed for 5 min by using an inbuilt pump. In this measurement process, the monitor is connected with bubbler attached to the sampling bottle using flexible tubing, and then the pump is running for 3 min so that the dissolve radon in water can escape into the tubing. Measurement has been taken in 15 min – cycle for 1 h. The variation of the radon concentration obtained in this study for Champhai district has been present in the range 0.53 Bq/l (surface water) to 17.67 Bq/l (spring water) with an average of 7.85 Bq/l in winter, 1.37 Bq/l (surface water) to 41.68 Bq/l (surface water) with an average of 16.25 Bq/l in summer and 1.52 Bq/l (surface water) to 30.23 Bq/l (surface water) with an average value of 10.17 Bq/l in monsoon. In Serchhip district, the variation of radon concentration has been present in the range 0.40 Bq/l (surface water) to 22.78 Bq/l (surface water) with an average of 3.19 Bq/l in winter, 8.84 Bq/l (surface water) to 29.69 Bq/l (groundwater) with an average value of 16.60 Bq/l in summer and 0.48 Bq/l (surface water) to 26.27 Bq/l (groundwater) with an average of 7.09 Bq/l in monsoon. The radon activity concentration in all the water samples has been found to be highest during summer followed by monsoon and lowest in winter for these two districts. The authors have observed that the average value of radon concentrations is higher in the groundwater than in the surface water, because of groundwater is enclosed and the radon content in groundwater is not released in to the ambient air. It is observed that the average values of radon activity of the water samples in winter and monsoon seasons of these two districts are below the USEPA's recommended MCL value of 11.1 Bq/l, while the average value of radon activity in the summer season is exceeding this MCL value. In summer, the average value of radon activities of water of Champhai and Serchhip districts is respectively about 1.46 and 1.50 times the USEPA's recommended MCL value. All the measured radon activity values are far below the WHO recommended action level of 100 Bq/l<sup>(54)</sup>. However, among all water sources selected in this study, the highest values of radon activity levels have been present respectively as 41.68 Bq/l and 30.23 Bq/l in summer and monsoon seasons in the surface waters only, the reason for the highest levels of radon found in surface waters has not been mentioned in this study.

From the above mentioned two studies, it is observed that the radon activity concentration in water of Mizoram state has been ranged 0.31 Bq/l to 41.68 Bq/l.

## 5.6 Orissa (or, Odisha)

The effect of radioactive contamination (due to Jaduguda U-mine) on the Subarnarekha River and tube-well waters in Mayurbhanj district of Orissa has been investigated by Ghosh et al.<sup>(44)</sup>. This contamination may results from the mining activity of Jaduguda U-mine, mentioned in this study. The authors have used CR-39 track detectors to estimate the alpha activity of the water samples. The SSNTDs have been attached with a glass rod stand that has been dipped into the water sample containing beaker. Exposure of CR-39 plates to alpha-particle radiations has been continued for 48 h. Authors have found the high levels of alpha activity in both river and tube-well waters in some locations which are located at distances far away from the U-mine area. In this study, the alpha activity level in tube-well waters along a part of the river path has been found in between 332 and 386 Bq/l. This study noted that the measured alpha activity values exceed the USEPA's recommended MCL

value of 11 Bq/l, and that also exceed the world average value of 10 Bq/l given by UNSCEAR<sup>(10)</sup> and WHO<sup>(59)</sup>. The alpha activity values reported in this study are found to be around 30 to 35 times the MCL value as set by USEPA, and also around 3.3 to 3.9 times the action level as recommended by WHO<sup>(54)</sup>. This study reported that the water system has been contaminated severely near the mine area due to leaching of uranium in huge amount, and the radioactive contamination level decreases with increasing the distances from the mine. So, the high level of alpha activity in drinking waters has been found in this area which is far away from the U-mine, but a decreasing trend in the water alpha activities has been seen in these locations along the river path.

Krishan and co-workers have determined the distribution of radon activity level in groundwater of coastal area in Baleswar (Balasore) district of this state<sup>(47)</sup>. The Durrige RAD-7 has been used to determine the radon activity level in the water samples. The radon activity values found in this study are ranging from  $1.6 \pm 0.21$  to  $17.0 \pm 1.69$  Bq/l with an average value of  $8.98 \pm 0.85$  Bq/l; and only three water samples examined in this study have activity more than the USEPA's recommended MCL value of 11.1 Bq/l. Their results revealed that 70% water samples have radon activity below the USEPA's recommended MCL value and 30% water samples have activity above the MCL value. It is observed that maximum activity level is about 1.5 times the MCL value. However, all the radon activity values measured in this study are far below the action level of 100 Bq/l as recommended by the WHO<sup>(54)</sup>.

It is observed from these two studies that the radon alpha activity of groundwater of the regions of these two districts ranges in between 1.6 and 386 Bq/l. Additionally, the alpha radioactivity of groundwater of coastal area is less than to the area along the river path.

## 5.7 West Bengal

Measurements of alpha radioactivity in 18 drinking water samples from different tube-well water points of 18 arsenic-prone areas in two districts of North 24 Parganas and South 24 Parganas have been carried out by Ghosh and his team<sup>(48)</sup>. Estimation of alpha activity level in water has been performed using CR-39 track detectors. The detector plates of approximate size  $2 \text{ cm}^2$  have been exposed to waters in 500 ml beakers of cross-sectional area of  $95 \text{ cm}^2$ . Exposure of CR-39 continued for 45 h. The authors have observed that the measured alpha activities vary from 39 to 220 Bq/l. In these two districts, minimum activity found at Palta in North 24 Parganas district while maximum found at Paschim Mallickpur Dhapdhapi in South 24 Parganas district. This study provides a positive evidence of the presence of high alpha activity in the drinking waters from arsenic-prone areas of these two districts. The analysis of this study indicate that the values of the alpha activity level in the severely arsenic contaminated waters of arsenic-prone areas are relatively high and varying in between 100 and 200 Bq/l which are respectively of 10 and 20 times larger than the world average of 10 Bq/l<sup>(10,59)</sup>. The authors concluded that arsenic and radioactive sources both coexist in certain areas of these two districts. It is observed from this study that all the alpha activity values in the drinking waters exceed the USEPA's recommended MCL value, and these values are around 3.5 to 19.8 times the MCL value. Additionally, more than 60% samples have alpha activities above the radon action level as recommended by the WHO<sup>(54)</sup>, and the activities are around 1 to 2.2 times the action level.

Ghosh and his team conducted another study for measuring the alpha radioactivity of 85 drinking water samples from 32 blocks in six districts of North 24 Parganas, South 24 Parganas, Nadia, Murshidabad, Malda and Kolkata where the selected areas of these six districts are densely populated and severely affected by arsenic contamination<sup>(43)</sup>. The CR-39 SSNTDs have been used in this study for alpha activity measurements. The SSNTDs have been hanged from a glass rod stand, and the glass rod has been dipped into the water sample taken in a beaker. Exposure to alpha-particle radiations has been continued for 45 h. The measured alpha activity values in the water samples examined in this study have been present in the range 8 to 800 Bq/l. It has been mentioned in this study that almost all the alpha activity values are much higher than the MCL value of 11 Bq/l as set by US-EPA<sup>(58)</sup> and that are also much higher than the world average value of 10 Bq/l given by UNSCEAR<sup>(10)</sup> and WHO<sup>(59)</sup>. Authors have seen that about 64% samples has alpha activity above the threshold limit for radon activity of 100 Bq/l of drinking water<sup>(54)</sup>. All the water samples (except, one sample) have alpha activity above the USEPA's MCL value, and these alpha activity values are around 2.9 to 72 times the MCL value. Additionally, the alpha activity of about 64% samples is around 1 to 8 times the WHO's recommended action level. Investigation of this study reveals that the severely arsenic contaminated drinking water is highly alpha active; and there is present a positive correlation of the alpha activity level with the arsenic level in these areas. Possible occurrence, origin and mobility of the alpha radioactive sources may be influenced by the local geology, geochemistry and hydrogeology of the alluvial aquifers in the regions, mentioned in this study.

The above mentioned Ghosh's two studies<sup>(43,48)</sup> provided a positive evidence of the presence of high alpha activity level in the severely arsenic contaminated drinking waters, and also provided a positive correlation between alpha activity and arsenic levels in groundwater in their studied areas. The Ghosh's research team has also established the coexistence of both arsenic and radioactive sources in their studied areas (overall correlation coefficient  $R = 0.63$ ). However, from these two studies, it is

evident that the severely arsenic contaminated drinking water is highly alpha active, and hence the severely arsenic-prone areas contain some sources of the alpha-particles emitters. So, other than arsenic, some heavy metals may also be coexisted with the alpha emitters in such contaminated areas. The correlation of the heavy metals with the alpha emitters in drinking waters of different sources has been reported in some studies<sup>(60,61)</sup>.

Effect of radioactive contamination (due to Jaduguda U-mine) on the river and tube-well waters in six locations of Paschim Medinipur district has been studied by Ghosh et al.<sup>(44)</sup>. The authors have used CR-39 track detectors to estimate the alpha activity of the water samples. The SSNTDs have been attached with a glass rod stand that has been dipped into the water filled beaker. Exposure of CR-39 plates to alpha-particle radiations has been continued for 48 h. The locations selected in this study are far away from the mine region. This study found the high level of alpha activities in the waters from river and tube-well water points located in the sampling sites. The activity level in the tube-well water samples has been found to vary from 336 to 476 Bq/l, which are above the USEPA's recommended MCL value and also above the world average value of 10 Bq/l set by UNSCEAR<sup>(10)</sup> and WHO<sup>(59)</sup>. The measured alpha activity values in the drinking water samples are found to be around 30 to 43 times the MCL value as set by USEPA, and these are respectively around 3.4 to 4.8 times the action level as recommended by WHO<sup>(54)</sup>. So, the high alpha-activity level in drinking waters has been present in the water points along the river path of Subarnarekha located in this district. This study reported that the water system is severely radioactivity contaminated near the U-mine area; this is because of the uranium leached in huge amount near the mine area. Authors have observed that the radioactive contamination effect decreases away from the mine area, and thereby a decreasing trend in the alpha activities of water has also been present in these sampling sites.

The radon activity levels in the drinking waters and bubbling gases of different springs at 7 different locations around the thermal springs at Bakreswar in Birbhum district have been reported in a study<sup>(24)</sup>. Radon concentration in the spring gas has been measured by using Alpha-Guard. To measure the radon concentrations in water, a parallel Alpha-Guard has been equipped with an appropriate unit (AquaKit), following a protocol proposed by the manufacturer. The radon activity concentration in the spring waters has been found to vary from  $3.18 \pm 1$  to  $46.9 \pm 5$  Bq/l. Results of this study revealed that the maximum radon activity value is about 4.2 times the MCL value as set by USEPA. However, results of this study revealed that the radon activity levels are much below the WHO's recommended action level of 100 Bq/l<sup>(54)</sup>. Authors of this study have observed that the area in and around the thermal springs has a high concentration of background radiation arising out of radon escape from the spring vents, direct release of gases out of the bubbling waters and from radon transferred through the surrounding soils.

Krishan and team<sup>(49)</sup> conducted a study to investigate the distribution of radon activity concentration in 20 groundwater samples from the east coast region of West Bengal. The radon activity in the water samples has been measured using Durrige RAD-7. The radon activity values in the samples have been found in between  $1.9 \pm 0.78$  and  $9.0 \pm 1.13$  Bq/l with an average value of  $5.0 \pm 0.83$  Bq/l. These values are well within the USEPA's MCL value of 11.1 Bq/l.

Identification of submarine groundwater discharge (SGD) in two districts of South 24 Parganas and East Medinipur (Purba Medinipur) in the east coast part of West Bengal has been performed by Krishan et al.<sup>(50)</sup>. The SGD is generally a combination of fresh groundwater and re-circulated seawater which is controlled by hydraulic gradient in the adjacent aquifer, and varying tidal conditions in the coastal waters. In this study, the drinking water samples have been collected from different hand pumps at 21 sampling points in the study area. The water samples have been collected in special glass bottles (250 ml capacity) designed for radon in-water activity measurement. The radon measurement in the water samples has been carried out using a radon-in-air monitor RAD-7 (Durrige Co. Ltd) using RAD H<sub>2</sub>O technique with closed loop aeration concept. The results of this study indicate radon activity of the water samples varies from 1.9 to 9.0 Bq/l with an average of 4.98 Bq/l. Continuous radon activity level recorded in this study clearly identifies the variation in SGD, apparently due to the increase in water level at low tides causing increased groundwater seepage and higher radon. The study indicates the large amount of groundwater is lost through its long coastline as well as discharge through long coastline in India.

It is observed in the above mentioned two studies<sup>(49,50)</sup> that the radon activity values in groundwater are almost equal and are also well within the USEPA's MCL value of 11.1 Bq/l. Among these two studies, the authors of a study<sup>(50)</sup> have observed that relatively high radon activities in the coastal waters are associated to the SGD.

Measurement of radon in 64 groundwater samples from tube-wells at different locations in Bakreswar geothermal province in Birbhum district has been carried out by Naskar and his team<sup>(51)</sup>. An Alpha Guard together with its accessories Alpha Pump and Aqua Kit has been used for measurement of radon activity of the water samples. The Alpha Guard has been operated in 1 min flow mode, and the pumping rate of Alpha Pump has been adjusted at 0.3 l/min. The pump has been kept on for 10 min, during which, after every one minute, the measurement returned by the radon monitor has been recorded by Data Expert software used with it. Minimum radon activity has been found as 3.3 Bq/l while maximum of that found as 355.2 Bq/l, with an average value of 83.2 Bq/l. This study reported that 95% groundwater samples have radon activities higher than the USEPA proposed MCL of 11.1 Bq/l<sup>(52)</sup>, and about 28% samples have radon activity levels significantly exceed the level of 100 Bq/l which is the

EU and WHO recommended reference and action levels<sup>(53,54)</sup>. So, this study has shown the relatively high level of radon alpha activity in drinking water from some tube-wells at Bakreswar area. The maximum radon activity value found in this study is 32 times the MCL value and it is also about 3.5 times the action level.

It is evident from the radioactivity data reported in the above mentioned seven studies for West Bengal state that the radon alpha-activity concentration in groundwater has been present in the range 1.9 to 800 Bq/l.

A comparison of the alpha activity values of the drinking waters of the regions of eastern part of India with the values of radon alpha activity of drinking waters of other parts around the India is shown in Table 3. It is clear from the Table 3 that the ranges of radon alpha activity level in the waters of eastern part of India are within the ranges of radon alpha activity of waters of other parts of India.

**Table 3.** Comparison of the radon alpha activity of drinking waters of eastern part of India with that of other parts around the India

Region	Radon alpha activity (Bq/l)	References
Gurgaon, Haryana	1.34 to 55.66	(62)
Budhakedar, Garhwal Himalaya	8 to 3047	(63)
Malwa belt, Punjab	5.01 to 11.6	(64)
Kumaon Himalaya	1 to 392	(65)
Mandya region, Karnataka	6.44 to 44.83	(66)
Hassan, Karnataka	0.85 to 60.74	(56)
Tumkur industrial areas, Karnataka	5.61 to 160.50	(57)
High and normal background radiation areas, Kerala	0.88 to 25.80	(67)
Some states, eastern India	0.31 to 911	[Present study]

Based on the radioactivity data reported in the above mentioned research studies for the seven states in the eastern part of India, the range of the radon alpha-activity of waters of different natural sources is tabulated in Table 2. In this table, the minimum and maximum radioactivity levels and the remarks for the high radioactivity are also presented. A distribution map of the radon alpha activity of waters in a pictorial form has been shown in Figure 1 for the seven states that mentioned in the published research studies. Two sizes (small and large) of 'dot' are used in this figure. Value of each small 'dot' is 5 Bq/l and that for large 'dot' is 50 Bq/l. The small size 'dot' represents maximum value of the radon alpha-activity level in waters found in the states of Assam, Meghalaya and Mizoram; whereas the large size 'dot' represents the maximum value of the radon alpha-activity of waters found in Bihar, Jharkhand, Orissa and West Bengal states. The lowest levels of the radon activity have been found to be present respectively at Diphu Town ( $0.46 \pm 0.03$  Bq/l) in the district of Karbi Anglong of Assam state and at a location ( $0.31$  Bq/l) of Aizawl district of Mizoram state, whereas the highest levels of radon alpha activity have been found to be present respectively at a location ( $911$  Bq/l) of Ganges basin of Bihar state and at Kalimandir Station Road ( $389.6$  Bq/l) of East Singbhum district of Jharkhand state.

Therefore, a wide variation of radon activity level, 0.31 to 911 Bq/l, in drinking waters has been found to be present in different natural water sources in the regions of eastern part of India. It is observed from the reports that the radon alpha radioactivity level in natural water varies from region to region in a state. This variation may be connected to the depth of the groundwater sources and the alpha-emitting radionuclides content in underlying rocks. The local geological features, geochemistry and hydrogeology of the aquifers can also influence the occurrence, origin and mobility of the radioactive sources in an area. The water radon activity is also correlated with the seismic activity in a region.

The value of radon alpha-activity of natural drinking water can be found with high level in some areas where the areas covered by geothermal springs and certain contaminants like arsenic and fluoride, or, the areas contaminated by the results of different human activities like uranium mining. The high level of the radon alpha radioactivity near the U-mine area may be attributed to the uranium mineralization and leaching of a large amount of uranium. The leaching of uranium from the U-mine can enhance the radon alpha activity of water from groundwater points near or/and even at far distances from the mine area. However, the high levels of radon alpha radioactivity in waters are found in some parts of Bihar, Jharkhand, Orissa and West Bengal states. So, in the radioactivity contaminated regions of these four states, the investigation on the background radiation level is thought to be necessary. Two studies have reported the high background radiation level in the Chhatrapur beach and Erasama beach placer deposits in Orissa state<sup>(68,69)</sup>. The U and Th containing materials of monazite and zircon sands are the major contributors to the high background radiation level in these two beach placer deposits. It may be noted that the mean values of natural background radiation levels in 1986 have been found as  $948 \pm 204$   $\mu$ Gy/y in Bihar state,  $1146 \pm 625$   $\mu$ Gy/y in Orissa state, and  $820 \pm 161$   $\mu$ Gy/y in West Bengal state<sup>(70)</sup>.

In Orissa state, the alpha activity of drinking water has been found relatively high value while the radon alpha activity found as low value. This finding is natural, because the alpha activity comprises both the solid alpha-emitters and the gaseous radionuclide of radon present in natural water. The radon alpha activity level in groundwater of the coastal area of Orissa is higher than that in West Bengal. On the other hand, relatively low level of radon alpha activity in drinking waters has been found in some water sources of the regions of Assam, Meghalaya, Mizoram and Orissa states as well as in the east coast region of West Bengal state. It is observed that the radon activity of groundwater of coastal area is less than to the area along the river path.

From the radiological protection point of view, routinely monitoring the drinking water quality in the highly radioactivity contaminated regions is important for safety of general population. However, the studies that have been reported the radon alpha-activity of natural drinking water in the regions of the eastern part of India are found sparse in case of Assam, Bihar, Jharkhand, Meghalaya, Mizoram and Orissa states. A number of such studies have investigated the radon alpha activity of waters for the state of West Bengal. But, such types of studies have not been found that have aimed for investigating the radon alpha activity of waters for the states of Arunachal Pradesh, Manipur, Nagaland, Sikkim and Tripura as well as also the union territory of Andaman and Nicobar Islands. More research studies or surveys regarding the radon alpha activity concentration in natural drinking waters of all water sources in the regions of eastern part of India are required to find possible other radioactivity contaminated areas.

## 6 Conclusions

A wide variation of alpha radioactivity level, 0.31 to 911 Bq/l, in natural drinking waters has been seen to be present in the regions of eastern part of India. The relatively high level of radon alpha radioactivity in groundwater has been present in certain regions of the states of Bihar, Jharkhand, Orissa and West Bengal. The relatively low level of radon in drinking waters has been present in some regions of Assam, Meghalaya, Mizoram and Orissa states as well as in the east coast region of West Bengal state.

The high level of radon alpha activity in drinking water can be found in some areas where the areas covered by the geothermal springs, arsenic and fluoride. Different human activities like uranium ore processing industry can result an enhancement of the radioactivity of natural water. The sources of the alpha-emitting radionuclides, arsenic and fluoride may coexist in the severely arsenic and fluoride contaminated areas. The radon alpha activity is correlated with the seismic activity in a region.

In a coastal region, the SGD can influence the alpha radioactivity levels in the groundwater and coastal water. The radon alpha activity concentration in the groundwater of coastal areas is less than that in the thermal spring, uranium mine and arsenic prone areas.

Studies on the radon alpha radioactivity of drinking water are sparse in Assam, Bihar, Jharkhand, Meghalaya, Mizoram and Orissa states. A number of such studies have been found for the state of West Bengal, particularly its southern part. Such relevant studies have not been found for the drinking waters in the regions of the states of Arunachal Pradesh, Manipur, Nagaland, Sikkim and Tripura as well as also in the union territory of Andaman and Nicobar Islands. More research studies or surveys regarding the radon alpha activity of drinking waters of all natural sources are required in the regions.

The radioactivity data presented in this study can help researchers working in the radioactivity field. This is the first ever attempt to overview the radon alpha activity level in natural waters of the regions.

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