Chapter 11
Environmental Implications of High Radiation in Beach Placers

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1 Introduction

One of the most attractive types of tourist destinations around the world is the beaches. The calming and soothing sound of the waves and the feeling of the silky sand at the feet attract millions of people to these destinations. The said silky sand which is a distinguishing feature of a beach, if not the most important one, is the topic of our discussion for this chapter. A number of important heavy minerals like illmenite, rutile, garnet, zircon, monazite and even metals like gold, cassiterite and platinum group of metals and even gem stones are economically exploited from these beaches. The assemblage of valuable minerals formed by gravity separation during the formation of sedimentary strata is termed as placer deposit. The beach areas which have a high concentration of these heavy minerals are known as beach placers. The Geelwal Karoo coastal placer deposits of South Africa are noted for its illmenite and garnet deposits (Macdonald and Rozendaal 1995). The Namakwa beach placer deposit of the west coast of South Africa is also noted for its zircon and gem stone deposits (Philander and Rozendaal 2015; Rozendaal and Philander 2000). In Brazil the Guarapari beach area is a popular tourist spot which is noted for its high radioactive dose rate values. According to Vasconcelos et al. (2013), the radioactive dose rate values of the area is almost 187 times higher than the prescribed limit by UNSCEAR (2000). This is mostly because of the presence of high concentration of the element thorium which is present in the mineral monazite. Monazite is a thorium phosphate mineral, which consists of 70% of Rare Earth Element oxides, 4–6% of thorium oxide and 0.15–0.25% of uranium oxide (Malarica et al. 1994). Apart from Guarapari several other beach areas of Brazil have a radioactive absorbed dose rate that is higher than the limit prescribed by the United Nations Scientific

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Committee on the Effects of Atomic Radiation (2000). Certain beach areas of Rio de Janeiro like Mambucaba and Buena; Meaipe and Anchieta areas of Espirito Santo (Veiga et al. 2006) have a high concentration of thorium which thereby results in a high radioactive dose rate values. The high thorium concentration has not only affected the beaches of Brazil but certain other beaches around the world as well. The Potenga beach areas of Chittagong, Bangladesh also shows a high concentration of thorium (Yasmin et al. 2018). The Miami Bay, Penang Island beach areas of Malaysia has monazite-rich black sand deposits and these areas show a high concentration of thorium and radium (Shuaibu et al. 2017). High concentration of thorium is also observed in certain samples of Hadhramout coast, Gulf of Aden, Yemen (Badran et al. 2016).

Almost 85% of the radiation that affects living population comes from the natural radionuclides (UNSCEAR 2000). Beach sands along with their heavy mineral content consist of these radionuclides, the proportion of which depends on the local geology of the beach area. Moreover beach sands are used for industrial and construction purposes, so natural radioactivity due to the presence of ^{238}U, ^{232}Th and ^{40}K should be measured. India has the second largest thorium deposits of the world and most of these deposits are present along the coastal regions of the country. In India the black beach sands of Kerala (UNSCEAR 2000) are already known for its high radioelement concentration. Along the south east coast of Tamil Nadu certain beach areas show a high concentration of thorium followed by uranium and potassium. In fact a close look along the eastern coastal region of the country shows that a high radioelement concentration, particularly a high thorium concentration, is prevalent along the beach areas. Apart from the beach areas of Tamil Nadu, the Bhimlipatnam and Ramakrishna beach areas of the state of Andhra Pradesh also show a high thorium concentration (Palaparthi et al. 2017). The beach areas of the state of Odisha have been extensively studied for its heavy mineral concentration and also to find the radioelement concentration. The beach areas of Ersama, Chhatrapur, Gopalpur, Garampeta, Markandi and also areas close to the mouth of the river Rushikulya show a high radioelemental concentration (Mohanty et al. 2003, 2004a, b; Rao et al. 2009; Ghosal et al. 2017). It is the high concentration of the element thorium which is the main reason behind the elevated radioelement concentration.

The primary reason behind this elevated thorium concentration is the surrounding geology of this area. The eastern side of the Indian subcontinent consists of a geological domain known as the Eastern Ghat Mobile Belt (EGMB) which consists of typical rock types: charnockite, khondalite, granite, migmatite and anorthosite (Ramakrishnan et al. 1998). These rock types particularly charnockite and khondalite consist of monazite and zircon as accessory mineral. The presence of thorium in monazite and uranium in zircon is the primary source of radioelements in the beach area. The constant weathering of these rock types of the EGMB by the surrounding river system is resulting in the transportation of the sediments to the beach area. The wave and tidal activities of the ocean results in the distribution of these sediments along the length of the beach. It is the presence of these sediments that results in the enrichment of the beach sands in heavy minerals containing monazite and zircon resulting in an elevated background radiation of the area.

Here we are going to talk about the High Background Radiation Areas (HBRA) along the eastern coastal region of the Indian subcontinent particularly the coastal areas of the state of Odisha. Studies conducted along certain beach areas of Odisha show a high background radiation value. For this purpose we are studying five beach areas (Ersama, Rushikulya, Chhatrapur, Garampeta and Markandi beaches) of Odisha and three beach areas of Andhra Pradesh (Sivasagar, Bhimlipatnam and Ramakrisha beach). The general objectives are as follows:

1. The assessment and concentration of radionuclides (U, Th and K) in the beach sands. It will help us to understand the subsequent environmental hazard associated with it.
2. The improper management of these beach sands is leading to the usage of these sands in construction purposes which is exposing a greater number of populations to the radiation associated with these beach sands. Hence, the radiological impact is calculated by computation of the radioactive dose rate.
3. A comparison between the radioactive data of the beach areas of Odisha and Andhra Pradesh has been discussed in order to find out the radiological potential of these areas.
4. Radium equivalent and Hazard Index estimation of these beach areas has been done.

2 Materials and Methods

Sand samples were collected along various beach areas of Odisha and Andhra Pradesh (Fig. 11.1). The samples were collected maintaining a northeast southwest trend. At each site the samples have been collected maintaining a gap between 500 m and 1 km. During collection, the top portion of the sand has been removed to avoid collecting rootlets and other anthropogenic objects. These samples collected from a shallow depth is dried and sieved through 0.355 mm in the laboratory. Then these samples are stored in glass air-tight vials and sealed to check for radon escape. The samples are then rested for a month to attain secular equilibrium.

2.1 Radiometric Analysis

The natural radioactivity of an area depends on a number of radionuclides, among them the most important ones are ^{232}Th, ^{238}U and ^{40}K. These radionuclides have been measured by γ-spectroscopic analysis. It is done in the Radiochemistry Division (BARC), Variable Energy Cyclotron Centre (VECC), Kolkata, India. Based on absolute method of analysis, activity concentration of uranium, thorium and potassium is measured. The analysis was done in GEM series High Purity Germanium (HPGe) coaxial detector, ORTEC, USA with 50% efficiency and 1.8 keV energy resolution at 1332 keV of ^{60}C. The detector efficiency has been calculated by using

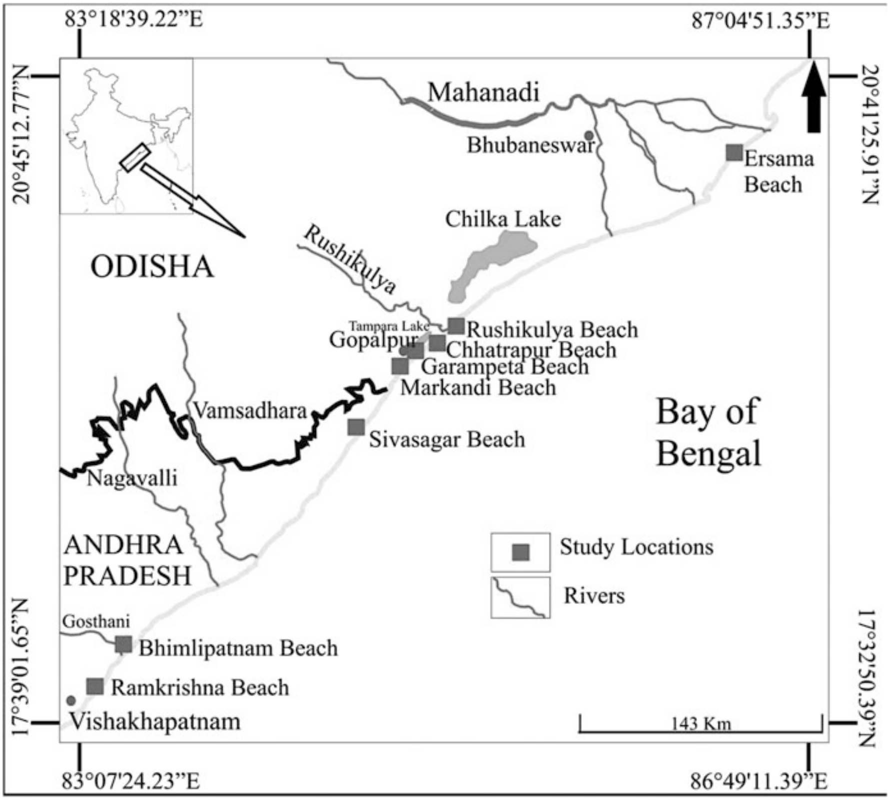

Fig. 11.1 Coastal areas of the eastern side of peninsular India. The various study areas along the beaches of Odisha and Andhra Pradesh have been marked by the square boxes. The relevant rivers and lakes have also been highlighted

^{152}Eu standard source of known activity with the help of Eq. (11.1). Potassium can be measured by its own γ-rays, but ^{232}Th and ^{238}U do not emit ϒ-rays directly. These can be measured by tracking the γ-rays emitted by their respective daughter products. Daughter products of ^{232}Th [338,911(^{228}Ac), 239(^{212}Pb), 727(^{212}Bi), 583 (^{208}Tl)] and ^{238}U [295,352(^{214}Pb) and 609(^{214}Bi)], are considered assuming a secular equilibrium status for the decay series. Each sample is measured for 40,000 s to obtain a reasonable ϒ-ray peak area. From this peak area the activity is measured with the help of a multi-channel analyser Canberra DSA 1000, which is connected to computer through Genie 2 K software.

$$\in = \frac{CPS \times 100}{A_t \times I} \tag{11.1}$$

where $\in$ = Efficiency, CPS = Counts per second, A_t = Activity of ^{152}Eu and I = Intensity of ^{152}Eu.

2.2 Absorbed Dose Rate

The radiation received by a person per kilogram of its mass is the absorbed dose rate by the person. The conversion factor required to calculate absorbed dose rate at 1 m above the ground surface, due to uniform distribution of gamma radiations from ^{238}U, ^{232}Th and ^{40}K is calculated by the method proposed by the UNSCEAR (2000). The equation is mentioned below:

$$D(\text{nGyh}) = 0.461A_{\text{U}} + 0.623A_{\text{Th}} + 0.0414A_{\text{K}} \tag{11.2}$$

where A_{U}, A_{Th} and A_{K} are specific activity of ^{238}U, ^{232}Th and ^{40}K in Bq kg^{-1}.

2.3 Annual Effective Dose Rate

Annual effective dose rate gives us an idea about the internal and external radiation exposure. It is calculated using the conversion coefficients (0.7 SvGy^{-1}) and 0.2 as the outdoor occupancy factor, as proposed by UNSCEAR (2000).

$$\text{AED}\left(\text{mSvy}^{-1}\right) = D\left(\text{nGyh}^{-1}\right) \times 8760\left(\text{hy}^{-1}\right) \times 0.2 \times 0.7\left(\text{Sv Gy}^{-1}\right) \times 10^{-6} \tag{11.3}$$

2.4 Radium Equivalent

Radium equivalent describes the gamma output from different mix of U, Th and K in samples and helps in comparison of radiation exposure due to different radioisotopes.

$$\text{Ra}_{\text{eq}} = A_{\text{U}} + 1.43A_{\text{Th}} + 0.077A_{\text{K}} \tag{11.4}$$

The equation is proposed by UNSCEAR (2000), based on the assumption that contributions from other radionuclides are insignificant.

2.5 Hazard Index

It is the index that indicates the external exposure due to the radioisotopes in the environment.

$$H_{ex} = A_U/370 + A_{Th}/259 + A_K/4810 \qquad (11.5)$$

$H_{ex} < 1$ is considered to be within limit, and $H_{ex} > 1$ is unsafe and equivalent to 370 Bq kg^{-1}.

3 Results and Discussion

All of these beaches show a high concentration of black particles in the beach sand and these particles appear in patches. The concentration of the individual radioelements of the area shows that the concentration of thorium is higher followed by potassium and uranium (Fig. 11.2). The average concentration of thorium is highest in the Ersama beach areas with values ranging between 900 and 4700 Bq/kg with an average of 2825 Bq/kg. Followed by Ersama the thorium concentration shows a decreasing trend towards the southwest direction along the coastal area. The average

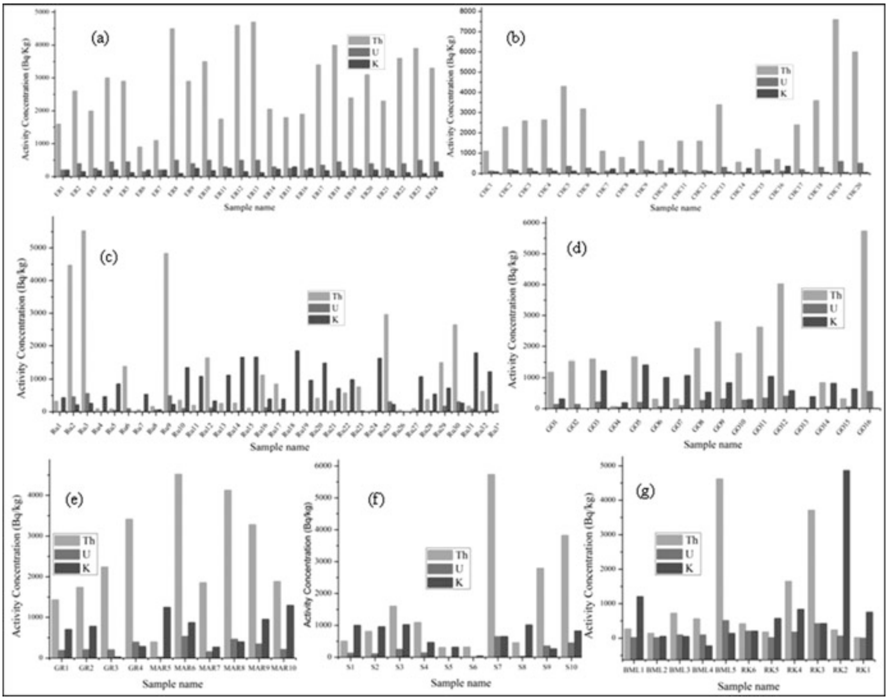

Fig. 11.2 Varying activity concentration of ^{232}Th, ^{238}U and ^{40}K along the eastern coastal beach areas of Odisha and Andhra Pradesh. Activity concentration of particular beaches are represented here: (**a**) Ersama Beach (Mohanty et al. 2004a); (**b**) Chhatrapur Beach (Mohanty et al. 2004b); (**c**) Rushikulya Beach (Rao et al. 2009); (**d**) Gopalpur Beach (Rao et al. 2009); (**e**) Garampeta and Markandi Beach (Ghosal et al. 2017); (**f**) Sivasagar Beach (Ghosal and Sengupta 2018); (**g**) Bhimlipatnam and Ramakrishna Beach (Palaparthi et al. 2017)

concentrations of thorium following the NE-SW trend along the beach areas of Chhatrapur, Rushikulya, Gopalpur, Garampeta, Markandi, Sivasagar, Bhimlipatnam and Ramakrishna beach are 2447, 1672, 991, 1845, 3133, 1745, 1263 and 1036 Bq/kg respectively. The average uranium concentrations of the study area along the beaches of Ersama, Chhatrapur, Rushikulya, Gopalpur, Garampeta, Markandi, Sivasagar, Bhimlipatnam and Ramakrishna are 358, 220, 201, 125, 204, 343, 211, 146 and 146 Bq/kg respectively. The activity concentrations of potassium from NE to SW along the Ersama, Chhatrapur, Rushikulya, Gopalpur, Garampeta, Markandi, Sivasagar, Bhimlipatnam and Ramakrishna beaches are 182, 130, 694, 854, 609, 756, 655, 242 and 1275 Bq/kg respectively. According to UNSCEAR (2000), the average ambient ^{232}Th, ^{238}U and ^{40}K values are 36, 33 and 474 Bq/kg. Almost all of the above mentioned beach areas show an average value of ^{232}Th, ^{238}U and ^{40}K greater than the permissible limit.

The average absorbed dose rate of the area along Ersama, Chhatrapur, Rushikulya, Gopalpur, Garampeta, Markandi, Sivasagar, Bhimlipatnam and Ramakrishna beach is 1932, 1631, 1161, 696, 1269, 2142, 1457, 864 and 766 nGy h^{-1}. The values are much higher than the prescribed limit of 55 nGy h^{-1}. The Gopalpur and Bhimlipatnam beach areas which are popular tourist spots also show an absorbed dose rate almost 21 and 16 times higher than the limiting value. The Annual effective dose rate value along NE to SW ranges between 4.9 and 0.03 mSvy^{-1} and the limiting value as proposed by UNSCEAR (2000) is 0.07 mSvy^{-1}. The average Radium Equivalent values of the beach area along Ersama, Chhatrapur, Rushikulya, Gopalpur, Garampeta, Markandi, Sivasagar, Bhimlipatnam and Ramakrishna beach are 4412, 3730, 1579, 2642, 2890, 4882, 2758, 1971 and 1727. Almost all of the Hazard Index values of the study area lie above the limiting value of 1 (Fig. 11.3a) which is the limit prescribed by UNSCEAR (2000).

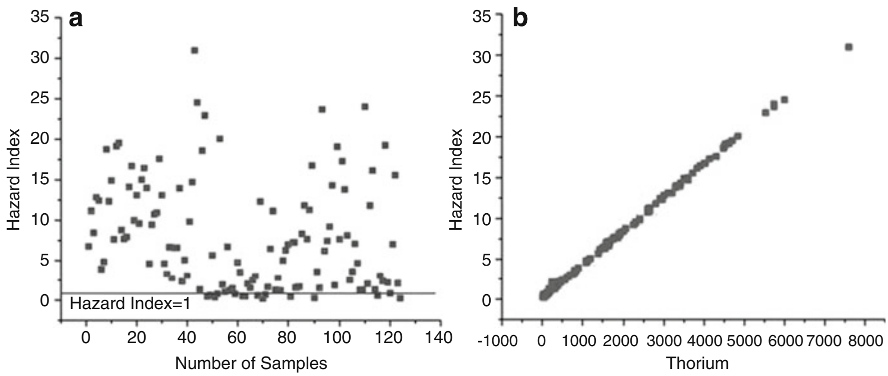

Fig. 11.3 (**a**) Hazard Index values of the various beach sand samples. Most of the samples show Hazard Index greater than one which is higher than the prescribed limit of UNSCEAR (2000). (**b**) A comparison of Hazard Index values with that of thorium concentration of the study area

From Fig. 11.1 it is observed that beach areas of Rushikulya and Gopalpur lie close to the mouth of the river Rushikulya, which is draining into the Bay of Bengal. The uranium concentration of these areas is relatively low as compared to the uranium concentration of the other beach areas (Fig. 11.2). This is because the presence of uranium in nature happens in mostly two states U^{+6} and U^{+4}; of these the +6 state is highly reactive and more prone to leaching as compared to the +4 state. In case of thorium which has only one state of Th^{+4}, it is insoluble in water (Aswathanarayana 1985).

It is evident from Fig. 11.2 that the study area has a dominant concentration of thorium when compared to uranium and potassium. The Radioactive Dose Rate and the Hazard Index of the area as observed in Figs. 11.3a and 11.4 show a high value which is harmful for the population living in the vicinity of these areas. In Fig. 11.3b a comparison between the Hazard Index values and the thorium concentration of the study area shows an absolute dependence of the hazard index values on thorium. A similar pattern is observed in case of the absorbed dose rate value (Fig. 11.4) of the area. When compared with the thorium concentration of the area it shows a positive correlation. Hence, it can be said with surety that the High Background Radiation (HBRA) values of the beach areas along the eastern coastal region of the Indian subcontinent is primarily dependent upon the thorium concentration of the study area. The presence of the mineral monazite containing thorium in its crystal lattice is the main contributing factor behind the high concentration of thorium. Also, the presence of the mineral xenotime which consists of thorium as reported by Behera (2003) and Subrahmanyam et al. (2004) along the study area can also be a contributing factor.

The illegal minning of these beach sands and their constant usage in construction purposes is an immediate threat that needs to be checked. Apart from the population that resides close to these beach areas being affected by these high radiation doses the usage of these sands in building construction is exposing a larger mass of people to the harmful effects of radiation.

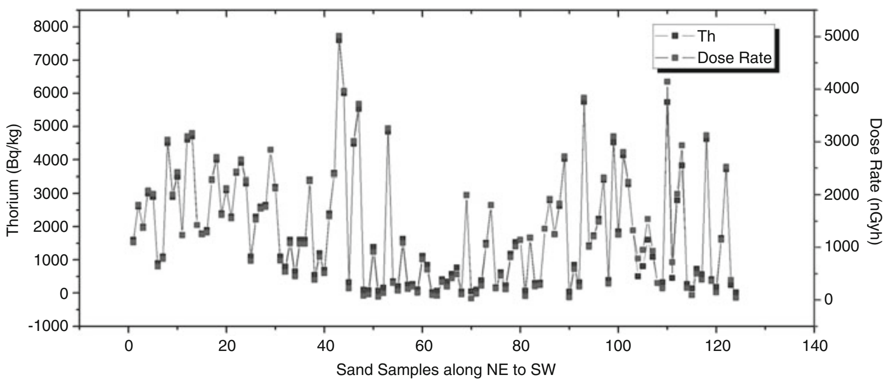

Fig. 11.4 Representation of the varying dose rates of the study area. The comparison between the absorbed dose rate and the thorium concentration of the study area shows a positive correlation

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