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Studies on natural and anthropogenic radionuclides in sediment and biota of Mumbai Harbour Bay

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Abstract Mumbai Harbour Bay (MHB) is a recipient of low level treated effluents from BARC, Trombay and its also a recipient of domestic and industrial wastes from the city of Mumbai and adjoining areas. Sediment samples were collected from various locations of MHB to determine the concentrations of naturally occurring radionuclides like ^{226}Ra, ^{228}Ra and ^{40}K which varied between 4.0 and 26.0, 5.5 and 19.9, 249.6 and 557.6 Bq $kg^{-1}_{(dry)}$ respectively and are comparable to the worldwide average concentration. The mean value ratio of ^{228}Ra/^{226}Ra in sediment was found to be 1.4, indicating a relatively higher mobility of ^{238}U compared to ^{232}Th. The concentration of anthropogenic radionuclide ^{137}Cs in sediment and biota ranged between 3.6 and 54.5 Bq $kg^{-1}_{(dry)}$, <0.08 and 0.5 Bq $kg^{-1}_{(wet)}$ respectively. The ingestion dose to 'General Public' due to ^{137}Cs intake is 0.02 μSv $years^{-1}$ which is negligible compared to the internationally accepted limit of 1,000 μSv $years^{-1}$ to 'members of public'.

Keywords Natural and anthropogenic radionuclides · Gamma spectrometry · Biota · Ingestion dose · Public dose limit · ^{228}Ra/^{226}Ra

Introduction

Every living creature in the environment is exposed to ionizing radiation and this radiation is part of the earth that comes from cosmos and affects all the goods, food and even the air we breathe. So, all living organisms are daily exposed to natural radiation that comes from the ground, building materials, air, food and even from the elements in their own bodies. Anthropogenic sources include those from fall out due to the atmospheric nuclear explosion experiments conducted during 1960s in western countries and that from operating nuclear installations. The study of natural radioactivity in marine and coastal environment gains significance for better management and protection of marine resources [1].

The main sources of natural radioactivity are ^{40}K and the radionuclides of uranium (U) and thorium (Th) decay series. The anthropogenic radionuclide ^{137}Cs which is globally distributed in the environment arises due to fallout of atmospheric nuclear explosions carried out in western countries.

The uptake of radionuclide by marine sediment depends on their physical and chemical properties. The radionuclides introduced into the aquatic system are subjected to dilution, dispersion, removal through sorption by bottom sediment and biota [2]. Most radionuclides are sorbed directly on to sediment within 1–2 years [3]. Sediment compartment acts as a sink for accumulation of radionuclides and it indicates the impact of pollution [4]. Radionuclides are reported to be more concentrated in fine-grained sediment than in coarse-grained sediment [5].

It is well established that in the oceans, both ^{226}Ra and ^{228}Ra are primarily derived from sediment by radioactive decay and a small fractions of it may be mobilized from the sediment [6]. Caesium in solution is a monovalent cation that seldom forms complexes under environmental conditions [7]. It is observed that ^{137}Cs is sorbed on to marine sediment with $k_d \approx 1{,}000$ and can be desorbed from it by sea water [8].

The aim of the present study is to determine natural (^{226}Ra, ^{228}Ra, ^{40}K) and anthropogenic (^{137}Cs) radioactivity

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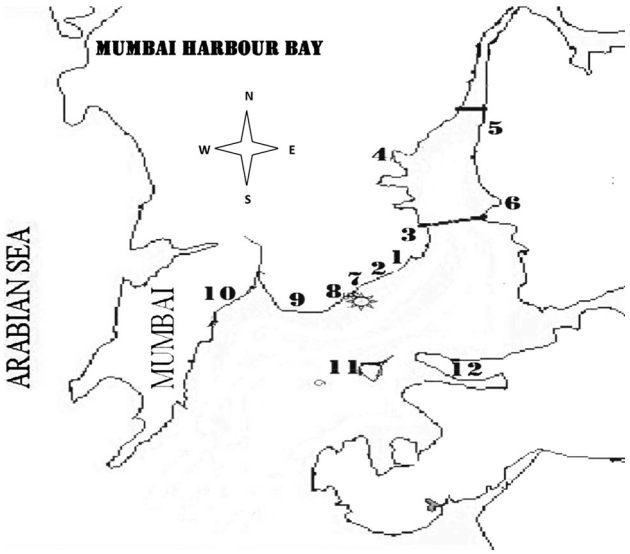

Fig. 1 Sampling locations of Mumbai Harbour Bay

levels in the sediment of MHB and to find out the mobility of radium. To assess risks to human health due to intake of marine biota, ingestion dose to public was computed using ^{137}Cs concentration of it in conjunction with relevant dietary intake surveys.

Description of sampling location

The study area MHB (lat. 18°53′–19°04′N, long. 72°48′–73°00′E) is located in the west coast of India is a recipient of low level treated effluents from BARC, Trombay and its also a recipient of domestic and industrial wastes from the city of Mumbai and adjoining areas. This funnel shaped bay is a land-locked mass of water concentrated at the broad southern end with the Arabian Sea. The narrow end of the bay is fed in the north to Ulhas, a fresh water region. The Ulhas river is connected with the bay through Thane Creek (Fig. 1). The Ulhas river flows into the Arabian sea through creek at the northeastern end of Salsette island and part of it flows through the Thane Creek into the bay. The Panvel river flows into the bay from the eastern mainland [9, 10]. The average area of the water surface of the bay is about 160 km^2 at low tide level and 215 km^2 at high tide level [9].

Sampling and sample preparation

Approximately 50–100 m away from the coast of MHB, sediment samples (0–20 cm depth level) were collected from twelve different location and biota [arca(4nos.), crab(4nos.), mudskipper(3nos.), fish(5nos.)] were collected from location 1 and 3 as shown in Fig. 1.

From each location, three subsamples of sediment were collected, combined, dried, pulverized and homogenized. These samples after drying in an oven at 110 °C for 48 h to ensure that moisture is completely removed. A known aliquot($\sim$250 g) was taken in a predefined geometry, sealed for a period of 1 month to assure secular equilibrium between ^{222}Rn (3.8 days) and its decay products ^{214}Pb (28.8 min),^{214}Bi (19.9 min) with ^{226}Ra (1,600 years) precursor in the sample and counted.

The various varieties of biota collected were separated into edible and non-edible parts. The edible parts were weighed, dried and powdered. A known aliquot was taken in a predefined geometry and counted for ^{137}Cs content.

Gamma-ray spectrometry

The concentration levels of natural and anthropogenic radionuclides were measured using a high purity germanium detector (p-type HPGe, relative efficiency 50 % and resolution 1.8 keV for 1,332.0 keV of ^{60}Co). The gamma ray transitions of energies 351.9 keV (^{214}Pb) and 609.3 keV (^{214}Bi) were used to determine the concentration of ^{226}Ra, while the gamma-ray lines at 911.0 keV (^{228}Ac) and 583.0 keV (^{208}Tl) were used to determine the concentration of ^{228}Ra. The gamma-ray transitions at 1,460.0 keV and 661.6 keV were used to determine ^{40}K and ^{137}Cs concentration respectively.

Ingestion dose calculation

In order to assess the radiation risk from ^{137}Cs, the annual effective ingestion dose due to consumption of biota was calculated, taking into account the ingestion dose conversion factor of ^{137}Cs and the annual consumption rate of biota. The formula used for ingestion dose is as follows

$$D_{\text{eff}} = A_i C_i R_f,$$

where D_{eff} is the annual effective ingestion dose (Sv years^{-1}), A_{i} is the concentration of ^{137}Cs in biota (Bq $\text{kg}^{-1}_{(\text{wet})}$), C_{i} is the ingestion dose conversion factor (Sv Bq^{-1}) and R_{f} is the annual consumption rate of biota (kg years^{-1})

Results and discussion

Table 1 represents the natural and anthropogenic radioactivity concentrations in sediment samples from MHB, obtained by direct gamma spectrometry measurements. The levels of ^{226}Ra, ^{228}Ra, ^{40}K were found to be in the range of 4.0–26.0 Bq $\text{kg}^{-1}_{(\text{dry})}$ (mean: 10.6 Bq $\text{kg}^{-1}_{(\text{dry})}$),

Table 1 Natural and anthropogenic radioactivity concentrations in sediment of MHB

Location	^{226}Ra Bq $kg^{-1}_{(dry)}$	^{228}Ra	^{40}K	^{137}Cs	^{228}Ra/^{226}Ra
1	10.3 ± 5.5	14.8 ± 3.9	424.9 ± 10.3	26.0 ± 0.2	1.4
2	10.3 ± 3.1	11.5 ± 4.8	359.4 ± 8.6	30.5 ± 0.9	1.1
3	12.7 ± 5.7	17.3 ± 3.7	429.7 ± 11.1	32.5 ± 1.1	1.4
4	26.0 ± 1.1	19.9 ± 4.1	507.6 ± 11.5	21.7 ± 1.2	0.8
5	11.8 ± 2.4	15.5 ± 3.2	530.2 ± 13.3	23.2 ± 1.4	1.3
6	4.0 ± 0.8	5.5 ± 1.4	249.6 ± 9.1	3.6 ± 0.9	1.4
7	12.1 ± 4.1	12.4 ± 2.3	493.5 ± 10.2	36.6 ± 1.1	1.0
8	14.5 ± 4.7	18.9 ± 3.6	557.6 ± 10.3	54.5 ± 1.1	1.3
9	5.4 ± 1.0	10.6 ± 1.9	385.3 ± 8.5	10.0 ± 0.9	2.0
10	4.3 ± 1.1	8.4 ± 1.5	437.1 ± 8.4	10.9 ± 0.9	2.0
11	4.3 ± 0.9	8.4 ± 1.5	424.2 ± 10.5	4.8 ± 0.9	2.0
12	11.8 ± 3.0	8.9 ± 1.3	433.1 ± 9.9	4.4 ± 1.0	0.8

Table 2 Radioactivity concentration of ^{137}Cs in biota and ingestion dose to 'general public'

Location	^{137}Cs concentration (Bq $kg^{-1}_{(wet)}$) in				Annual effective ingestion dose to 'General Public' (μSv $years^{-1}$)
	Arca	Crab	Mudskipper	Fish	
L1	0.2 ± 0.01	0.2 ± 0.01	–	0.2 ± 0.01	0.02
	<0.08	0.3 ± 0.01		0.1 ± 0.01	
L3	<0.08	<0.08	<0.08	<0.08	
	<0.08	<0.08	<0.08	<0.08	
	–	–	0.5 ± 0.01	<0.08	

5.5–19.9 Bq $kg^{-1}_{(dry)}$ (mean: 12.7 Bq $kg^{-1}_{(dry)}$) and 249.6–557.6 Bq $kg^{-1}_{(dry)}$ (mean: 436.0 Bq $kg^{-1}_{(dry)}$) respectively and are comparable with the average worldwide concentrations of 25.0 Bq kg^{-1} (for ^{238}U), 25.0 Bq kg^{-1} (for ^{232}Th), 373.0 Bq kg^{-1} (for ^{40}K) respectively [11].

However, the ^{228}Ra/^{226}Ra ratio observed in the present study ranged between 0.8 and 2.0 with an average ratio of 1.4, which is moderately above the world's average (1.0). This can be attributed to the relatively greater mobility of ^{238}U compared to ^{232}Th [12].

The anthropogenic radionuclide ^{137}Cs concentration in sediment varied between 3.6 and 54.5 Bq $kg^{-1}_{(dry)}$ (mean: 21.6 Bq $kg^{-1}_{(dry)}$) is similar to that observed in ^{137}Cs studies on sediment at Turkey [13] and Albania [14]. Table 2 details the concentration of ^{137}Cs observed in different biota samples which has ranged between <0.08 and 0.5 Bq$kg^{-1}_{(wet)}$ (mean: <0.08 Bq $kg^{-1}_{(wet)}$) and it is similar to that observed along the Brazilian coast (0.1–0.3 Bq kg^{-1}) [15], coast of Spain (0.08–0.2 Bq kg^{-1}) [16], coast of Greece (0.1–0.2 Bq kg^{-1}) [16] and also the study area (0.09–0.5 Bq kg^{-1}) by earlier researchers [17]. The average estimated ingestion dose to 'general public' due to consumption of biota is 0.02 μSv $years^{-1}$, which is negligible when compared to the internationally accepted dose limit of 1,000 μSv $years^{-1}$.

Conclusions

The radioactivity levels of ^{226}Ra, ^{228}Ra and ^{40}K observed in sediments of MHB are comparable with the average worldwide reported concentration level. Moderately higher value of ^{228}Ra/^{226}Ra ratio indicates that the distribution of ^{228}Ra and ^{226}Ra are functions of their parents ^{232}Th and ^{238}U respectively. The estimated internal dose received by the 'general public' is a small fraction (0.0008 %) of the average annual effective dose due to exposure to natural radiation sources-2.4 mSv [18] and also a very small fraction (0.002 %) of the public dose limit (1000 μSv years) set by agencies like ICRP and AERB (National Regulatory Agency).

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