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Study on the Distribution and Bioaccumulation of Natural Radionuclides, ^{210}Po and ^{210}Pb in Parangipettai Coast, South East Coast of India

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Water, sediment and Biota (plankton, seaweeds, prawn, crabs, gastropods, bivalves and fish) samples collected from the study region were subjected to analyses of ^{210}Po and ^{210}Pb. It showed non-uniform distribution of these radionuclides in the biota, in a descending order: molluscs > crustaceans > fishes. Concentration of ^{210}Po and ^{210}Pb were 1.65 mBq/l and 3.38 mBq/l in water samples and 4.38 Bq/kg and 2.31 Bq/kg in sediment samples respectively. Soft tissues and muscle of animals accumulated higher level of ^{210}Po while shells and bones contained more ^{210}Pb. Bivalve mollusc *Perna viridis* accumulated higher levels of both ^{210}Po and ^{210}Pb thus suggesting that this species can serve as a bioindicator in marine environment. Concentration factor of ^{210}Po for the biotic components ranged from ~ 10^3 to ~10^4 while for ^{210}Pb it ranged from ~ 10^2 to ~ 10^3.

[**Keywords:** Radionuclide, Parangipettai coast, ^{210}Po and ^{210}Pb]

Introduction

Among the natural radionuclides, alpha emitter, ^{210}Po and beta emitter, ^{210}Pb of the ^{238}U series are of radioecological interest for a number of reasons. This is mainly because of its large contribution to the natural radiation dose received by many species[1,2]. ^{210}Pb and its descendent ^{210}Po are members of the ^{238}U natural radioactive series. They are supplied to sea water through atmospheric input, rivers and run-off and the in situ decay of ^{226}Ra precursor in the water column. Atmospheric ^{210}Pb derives from the decay of ^{222}Rn, emanating from terrestrial rocks. In sea water, Lead and Polonium are non-conservative in their distribution being dependent on their association with suspended particles and biological cycles. Surface coastal waters display higher concentration of ^{210}Po and ^{210}Pb. The main source of ^{210}Po and ^{210}Pb entering into the environment is through the exhalation of ^{222}Rn from the ground scientific investigation on the distribution and bioaccumulation natural radionuclides in the marine province of Parangipettai coastare a few. Parangipettai coast is a prominent fishery centre and a nursery ground for variety of fish and invertebrate.

Materials and Methods

River Vellar debouches into north Bay of Bengal thorugh Parangipettai coast. It is located 233 km south of Chennai city (Lat. 11° 29′ N; Long 79° 46′ E) Fig. 1. water, sediment, seaweeds, net plankton, five species of prawns (*Penaeus indicus, P. monodon, P. semisulcatus, Metapenaeus dobsoni and M. monoceros*) four species of crabs (*Portunus sanguinolentus, P. pelagicus, Charybdis cruciata and Scylla serrata*) two species of gastropod molluscs (*Xancus pyrum, Murex tribulus*) four species of bivalves (*Perna viridis, Meretrix meretrix, Anadara granosa, Crassostrea madrasensis*) and fifteen species of fishes (*Lepturaccanthus savala, Rastrelliger kanagurta, Carangoides malabaricus, Cynoglossus macrolepidotus, Upeneus trangula, Argyrops spinifer, Mugil cephalus Sillago sihama, Therapon jarbua, Platycephalus indicus, Sardinella longiceps, Alepes mate, Chanos chanos, Arius caelatus, Liza subviridis*) were chosen for analysis in the present study.

^{210}Po determinations were made by the standard technique of acid digestion. Spontaneous deposition of ^{210}Po from an acid solution on to both sides of a polished silver disc and counting of the ^{210}Po alpha activity on the disc[3,4]. ^{210}Pb was estimated by allowing equilibrium growth of Bi-210 ($T_{1/2}$=5d) separation of $BiPO_4$ and counting in a low beta counter[5]. The counting instruments used were an alpha counter with ZnS (Ag) detector with a background of 0.1 - 0.2 cpm and a counting efficiency of 25% and a low beta counter with a background of 1.5 to 2.0 cpm and an efficiency of 40%.

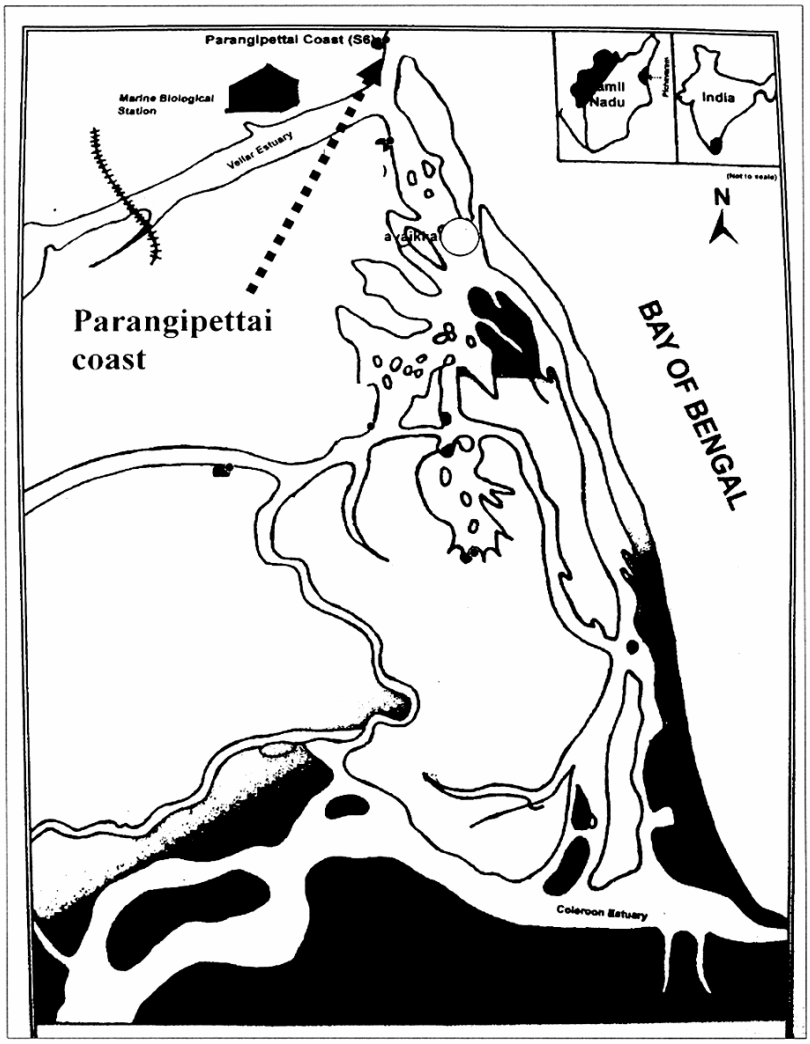

Fig. 1—Study area showing the Bioaccumulation of Natural Radionuclide

Results

The concentrations of ^{210} Po and ^{210}Pb in water, sediment, plankton, seaweeds, prawns, crabs, gastropod, bivalves and fishes were selected and analysed in the Parangipettai coast (Table 1-2 and Figs. 2-3). concentrations of ^{210}Po and ^{210}Pb in Parangipettai coastal waters are in the range of 0.70 to 2.75 mBq/l (mean: 1.65 mBq/l) and 2.57 to 4.71 mBq/l (mean: 3.38 mBq/l) respectively. The activity of ^{210}Po and ^{210}Pb in sediment samples ranged form 1.99 Bq/kg to 6.19 Bq/kg (mean: 4.38Bq/kg) and 1.01 to 3.70 Bq/kg (mean: 2.31 Bq/kg) respectively. The results of ^{210}Po and ^{210}Pb analyses for plankton in near shore water of the Parangipettai coastal environment the ^{210}Po activity in plankton ranged from 42.6 to 88.3 Bq/kg wet (mean: 96.21 Bq/kg) and the activity of ^{210}Pb ranged from 16.23 to 35.20 Bq/kg wet (mean: 21.12 Bq/kg). There are three species of seaweeds in Parangipettai coastal environment. The concentration of ^{210}Po in seaweeds ranged from 16.2 to 19.22 Bq/kg (mean: 16.50 Bq/kg) and the activity of ^{210}Pb ranged form 7.2 to 12.10 Bq/kg (mean: 9.60 Bq/kg).

Among aquatic organisms, the general pattern of accumulation observed was that ^{210}Po concentrated in the soft tissues/muscle to a higher degree. ^{210}Pb concentrated more in exoskeleton/shells/bones. Concentrations of ^{210}Po and ^{210}Pb in crustaceans ranged from 25.63 to 96.61 Bq/kg in the muscle and from 4.51 to 46.91 Bq/kg in the exoskeleton; ^{210}Pb ranged from 0.97 to 2.12 Bq/kg in muscle and 2.41 to 11.42 Bq/kg in the exoskeleton respectively. The ^{210}Po concentrations in soft tissue vary from 40.10 to 132.40 Bq/kg. In shells they ranged from 2.12 to

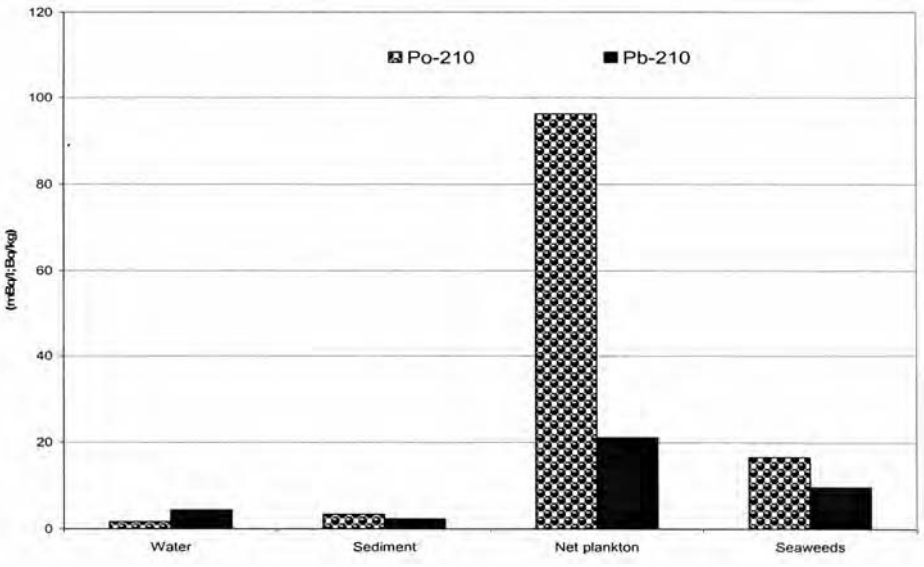

Fig. 2 —Concentrations of ^{210}Po and ^{210}Pb in the water, sediment, net plankton and seaweeds of Parangipettai coastal environment.

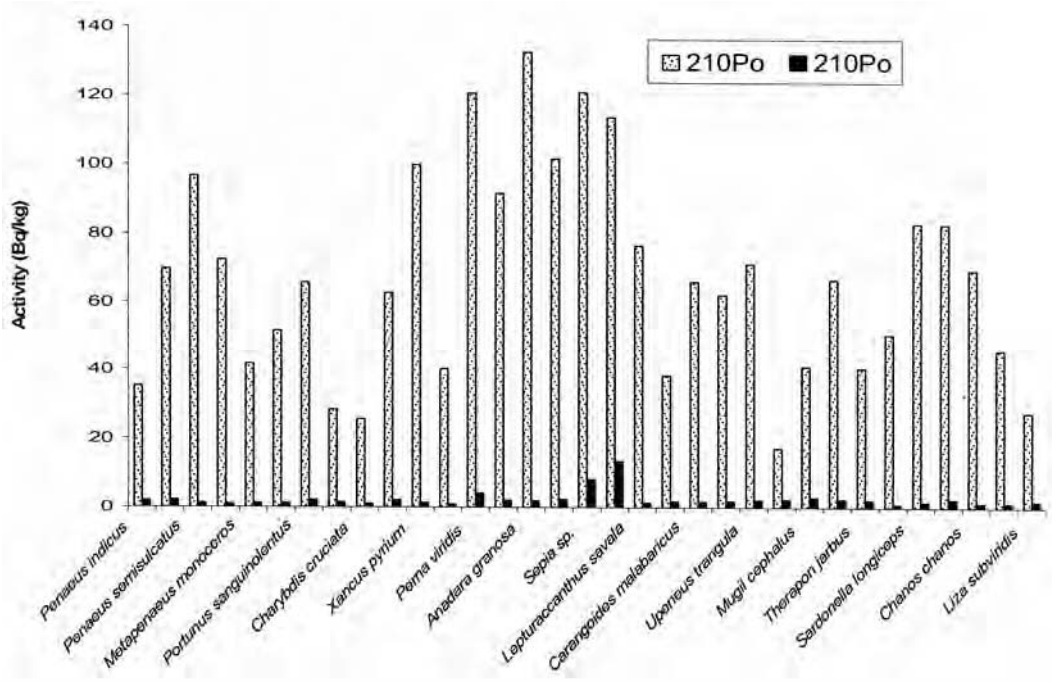

Fig. 3 — Concentrations of ^{210}Po and ^{210}Pb in the prawns, crabs, gastropods, bivalves and fishes of Parangipettai coastal environment.

15.20 Bq/kg. The ^{210}Pb concentrations in soft tissue vary from 0.9 to 4.20 Bq/kg . In shells it ranged from 4.2 to 12.40 Bq/kg respectively. Bioaccumulative ability in bivalve species with reference to ^{210}Po was observed to be highly variable among the species analysed. *Perna viridis* registered maximum level (120.6-309.0 Bq/kg) and *Anadara granosa* the minimum level (82.10-170.30 Bq/kg) in the soft tissues. Analyses of ^{210}Pb show that the concentration is always higher in the shell than in the total soft tissue of bivalves.

The ^{210}Po and ^{210}Pb contents of the muscle and bone of the fish of Parangipettai coastal environment they were selected in fifteen species of fishes analysed. The ^{210}Po concentrations in the muscle ranged from 17.20 to 82.90 Bq/kg (mean: 55.79 Bq/kg) and in bones from 4.93 to 28.10 Bq/kg (mean: 11.63 Bq/kg). In all the fish analysed higher

Table 1—Concentration of ^{210}Po and ^{210}Pb in the water, sediment, plankton, seaweeds and crustaceans of Parangipettai coastal environment.

Samples		^{210}Po (Bq/kg)	^{210}Pb (Bq/kg)
Water (mBq/l)		0.70-2.75	2.57-4.71
		1.65±0.63	3.38±0.67
Sediment		1.99-6.19	1.01-3.70
		4.38±1.50	2.31±0.83
Plankton		42.6-88.3	16.23-35.2
		96.21±5.65	21.12±2.89
Seaweeds		16.2-19.22	7.2-12.10
		16.5±2.25	9.6±2.19
		Crustaceans	
Prawns			
Muscle	Range	35.10-96.61	0.97-2.10
Mean	Mean	63.04±24.98	1.48±0.49
Exoskeleton	Range	9.23-46.91	4.10-11.40
	Mean	24.40±14.32	7.45±2.68
Crabs			
Muscle	Range	25.63-65.61	1.11-2.12
	Mean	45.52±21.52	1.70±0.50
Exoskeleton	Range	4.51-14.81	2.41-11.42
	Mean	11.26±4.81	5.45±4.07

No. of Analyses (n) = 8

Table 2 — Concentration of ^{210}Po and ^{210}Pb in the molluscs and fishes of Parangipettai coastal environment.

Samples		^{210}Po (Bq/kg)	^{210}Pb (Bq/kg)
		Molluscs	
Gastropods			
Soft	Tissue	40.1-99.7	0.9-1.4
Range	Mean	69.9±34.41	1.15±0.29
Shell	Mean	2.12-6.2	4.2-6.3
Range		4.16±2.36	5.25±1.21
Bivalves			
Soft	Tissue	91.6-132.40	1.91-4.20
Range	Mean	111.5±18.42	2.63±1.06
Shell	Mean	3.90-15.20	4.90-12.40
Range		7.25±5.33	9.45±3.29
		Fishes	
Muscle	Range	17.20-82.90	0.92-2.91
	Mean	55.79±20.26	1.95±0.51
Bone	Range	4.93-28.10	3.10-19.20
	Mean	11.63±6.27	8.44±4.91

No. of Analyses (n) = 8

^{210}Po contents were found in the muscle of *Sardonella longiceps* (82.90 - 110.30 Bq/kg), *Upeneus trangula* (71.10 - 91.12 Bq/kg) and *Alepes mate* (67.10 - 99.30 Bq/kg) than in other fishes. The ^{210}Pb concentration in the muscle of fishes ranged from 0.92 to 2.91 Bq/kg (mean: 1.95 Bq/kg) and in bone from 3.10 to19.20 Bq/kg (mean: 8.44 Bq/kg). However, the bone of *Mugil cephalus* (5.12 - 26.90 Bq/kg), *Carangoides malabaricus* (8.11 - 15.70 Bq/kg), and *Sardonella longiceps* (6.12 - 18.20 Bq/kg) showed relatively enhanced levels of ^{210}Pb accumulation and the mean concentrations of ^{210}Pb in muscle and bones of fishes are also presented in Fig. 2.

Concentration factors calculated for ^{210}Po and ^{210}Pb in plankton, seaweeds, prawns, crabs, gastropods, bivalves, and fishes are presented in Table 3. Concentration Factor = Concentration in Biota (Bq/g) /Concentration in water (mBq/l). Concentration factors determined for the Parangipettai coast biota were within the following ranges:

Table 3—Concentration factor of ^{210}Po and ^{210}Pb in the biota of Parangipettai coastal environment.

Sample		Concentration factor (CFs)* ^{210}Po	^{210}Pb
Plankton		5.8×10^4	6.2×10^2
Seaweeds		1.0×10^2	2.8×10^2
		Crustaceans	
Prawns	Muscle		
		3.8×10^4	4.3×10^3
Eoskeleton		1.4×10^4	2.2×10^3
Crab	Muscle	2.7×10^4	5.0×10^2
		6.8×10^3	1.6×10^3
Eoskeleton			
		Molluscs	
Gastropods tissue	Soft		
		4.2×10^4	3.4×10^2
	Shell	2.5×10^3	3.1×10^3
		6.7×10^4	7.7×10^2
Bivalves tissue	Soft	4.3×10^3	2.7×10^3
	Shell		
		Fishes	
	Muscle	3.3×10^4	5.7×10^2
	Bone	7.0×10^3	2.4×10^3

*Concentration Factor = Concentration in Biota (Bq/g)/ Concentration in water (mBq/l)

		CF of ^{210}Po	CF of ^{210}Pb
Plankton		~10^4	~10^3
Seaweed		~- 10^2	~10^2
Prawns	Muscle	~10^4	~10^2
	Exoskeleton	~ 10^4	~10^3
Crabs	Muscle	~10^4	~10^2
	Exoskeleton	~10^3	~ 10^3
Gastropods	Soft tissue	~10^4	~10^2
	Shell	~10^3	~ 10^3
Bivalves	Soft tissue	~10^4	~10^2
	Shell	~ 10^3	~10^3
Fish	Muscle	~ 10^4	~10^2
	Bone	~10^3	~ 10^3

Discussion

^{210}Po concentration in coastal water samples ranged from 0.70 mBq/l to 2.75 mBq/l with the mean value of 1.65 mBq/l. ^{210}Po level recorded in Parangipettai coast was slightly higher than the level observed in Palk strait[6] (1.54 mBq/l), but lower than the levels reported for other near by coasts ie, 2.4 - 32.4 mBq/l in Gulf of Mannar[7], 6.6 mBq/l at Kalpakkam coast[8] and 1.8 mBq/l at Pichavaram Mangrove forest[9]. The concentration of ^{210}Pb in Parangipettai ranged from 2.5 to 4.71 mBq/l and these values were much lower than the level observed in Gulf of Mannar[10] (34.18 mBq/l).

^{210}Pb activity in water sample was higher than that of ^{210}Po activity. Higher ^{210}Po activity in Gulf of Mannar[10] linked to the presence of monazite found on beach placer. Low level of ^{210}Po at the Parangipettai coast may be related to the quantitative difference in the distribution of radioactive mineral deposits in the adjoining area. Activity of ^{210}Pb in the sediment samples ranged from 1.01 to 3.7 Bq/kg (mean value of 2.31 Bq/kg) which is much less when compared to the sediments of Gulf of Mannar (35.3 Bq/kg)[7], Kalpakkam (385 Bq/kg)[11] and Trombay coast (356 Bq/kg)[12].

Concentrations of ^{210}Po and ^{210}Pb in the seaweeds were found to be in the range of 14.23 - 19.22 Bq/kg and 7.20 - 12.1 Bq/kg respectively. Among the seaweeds, Padina *gynospora* displayed high ^{210}Po level (19.22 Bq/kg) than other seaweeds. In this value high, ^{210}Pb in the seaweeds of Gulf of Mannar[7] the recorded an accumulation in seaweeds ranging from 7.20 to 16.51 Bq/kg with mean values of 11.32 Bq/kg. In general the levels of ^{210}Pb were lower than those of ^{210}Po in all the species of seaweeds examined. Plankton samples the primary producer's shoed higher levels of ^{210}Po and ^{210}Pb, mean value ^{210}Po and ^{210}Pb concentration in plankton were observed to be 96.21 Bq/kg and 21.12 Bq/kg respectively. The recorded values were higher compared to those from the adjacent coast of Gulf of Mannar: ^{210}Po, 73.7 Bq/kg; ^{210}Pb, 20.2 Bq/kg[7]. High activity of ^{210}Po in the plankton may be due to the minute size with greater surface area for absorption. Phytoplankton and zooplankton which contribute to the large biological surface area of water bodies exhibit highest concentration factors and turn over rates for many trace elements[13].

Among aquatic organisms, the general pattern of accumulation was as given between ^{210}Po concentrated more in the soft tissues, while ^{210}Pb accumulated to a higher degree in shells and bones. Bioaccumulation of ^{210}Po in marine organisms of the Parangipettai coast followed a descending order: Molluscs > Crustacean > Fishes. The trend of ^{210}Po accumulation in crustacean soft parts appeared to be quite similar to that of molluscs. In the present study ^{210}Po concentration in prawn muscles ranged from 35.1 to 96.61 Bq/kg (mean value 63.04 Bq/kg) and in crabs, from 25.63 to 65.61 Bq/kg (mean value 45.52 Bq/kg). The ^{210}Po concentrations in exoskeleton of prawns ranged from 9.23 to 46.91 Bq/kg (mean value 24.4 Bq/kg), and in crabs from 4.51 to 14.81 Bq/kg (mean value 11.26 Bq/kg). These values are higher than ^{210}Po levels of Palk Strait [6] crustaceans which in muscles ranged from 16.20 to 80.3 Bq/kg and in exoskeleton from 11.30 to 67.10 Bq/kg. ^{210}Po concentration in muscle of prawn from Kalpakkam was 12.3 Bq/kg, while the corresponding figure for exoskeleton was 30.6 Bq/kg[11]. Baltic Sea[2] observed the concentrations of ^{210}Po in prawns in the range of 11.6 to 18.8 Bq/kg. They opined that the level of ^{210}Po in water, and more precisely the extent to which ^{210}Po is bound to dissolve organic matter, may be an important factor in determining the mechanisms of ^{210}Po accumulation by organisms.

^{210}Pb concentrations in prawn muscle ranged from 0.97 to 2.1 Bq/kg (mean value 1.48 Bq/kg) and in crab from 1.11 to 2.12 Bq/kg (mean value 1.70 Bq/kg). ^{210}Pb concentrations in exoskeleton of prawns ranged from 3.92 to 13.50 Bq/kg (mean value 7.45 Bq/kg) and in crabs from 2.41 to 17.63 Bq/kg (mean value 5.45 Bq/kg). These values were higher than those of the crustaceans from Palk Strait[6]. Average ^{210}Pb level in prawns of Mediterranean Sea

was 0.024 Bq/kg[1] in the prawns and crabs of Kalpakkam coastal waters, ^{210}Pb ranged from 0.22 to 1.2 Bq/kg for muscle and 0.78 to 2.4 Bq/kg for exoskeleton[11]. Higher concentration of ^{210}Pb in exoskeleton than in muscle is probably due to the capacity of lead to replace calcium[14]. Prawn undergoes a phenomenon of ecdysis or periodic moulting of exoskeleton. This shedding of the exoskeleton and formation of new one could possibly be attributed for the lower level of ^{210}Po in the exoskeleton of prawn.

^{210}Po levels in the molluscan species are presented in Table 2. In gastropod and bivalve soft tissues ^{210}Po ranged from 40.1 to 99.7 and 91.6 to 132.4 Bq/kg whiles in their shells the range from 2.12 to 6.2 and 3.9 to 15.2 Bq/kg). On the other hand ^{210}Pb levels were higher in shells (4.2 to 12.4 Bq/kg) than in soft tissue (0.9 to 4.2 Bq/kg). It is evident that invariably, the soft parts tended to have a rich accumulation of ^{210}Po but equally significant was the virtual exclusion of ^{210}Po in the shell. Among the molluscs gastropods reported lower level of accumulation of radionuclides, while bivalves accumulated high level of ^{210}Po. Variability in the accumulation was evidently based on the availability of ^{210}Po in the environment. Results suggest the possibility of using bivalves as bioindicators of radionuclides in a marine habitat. Gastropods feed chiefly, if not entirely on vegetation whereas bivalves feed on organic particulates, which are enriched with ^{210}Po. Work of[2,15,10,7,16 & 6] on the accumulation pattern of ^{210}Po in various invertebrate species also confirm the results of the present study.

The accumulation of ^{210}Po in shell recorded a decisive decline while that of ^{210}Pb shot up considerably. ^{210}Pb is a bone seeker and is incorporated in bone and shell replacing calcium and it has a long residence time in skeleton[14]. The soft tissues of the bivalve molluscs, *Perna viridis* and *Crassostrea madrasensis* concentrated a higher level of ^{210}Po (111.5 Bq/kg) than the soft tissues of gastropod species (66.9 Bq/kg). The concentration of ^{210}Po in soft tissue of brown mussel, *Perna indica* as 1939.2 Bq/kg (fresh wt.)[7], but in the present study recorded a lower level of ^{210}Po (120.6 Bq/kg dry) in total soft tissues of the green mussel *Perna viridi* could be observed. The results of the present study provided evidence to suggest that the soft tissues of green mussel *Perna viridis* could be used as an effective biomonitor of ^{210}Po radionuclide in a marine system and the shells of these organisms could serve as biomonitors for ^{210}Pb radionuclide

Concentration of ^{210}Po in fish muscle was observed to be in the range of 17.20 to 82.90 Bq/kg (mean value 55.79 Bq/kg) and in bone from 4.93 to 28.10 Bq/kg (mean value 11.63 Bq/kg) (Table 2). These values were lower than those reported for the muscle of fishes from adjacent coast, Gulf of Mannar[10,7], Palk Strait[17,6] and Kalpakkam Coast[4]. In all the fishes analysed the highest ^{210}Po concentration was recorded in the muscle of *Sardinella longiceps* a detrivore bottom feeder[17]. Higher concentration of ^{210}Po observed in this fish can be correlated to its plankton feeding habit. In general, plankton register a higher level of accumulation of ^{210}Po [18]. As ^{210}Po has a high degree of association with organic moiety of fish which feeds on organic detritus there is a tendency to accumulate higher level of ^{210}Po in their muscle. Further direct absorption of ^{210}Po through gills takes place in addition its entry through food[2].

^{210}Pb activity of muscle ranged from 0.92 to 2.91 Bq/kg (mean value 1.95 Bq/kg) and in bone it ranged from 3.10 to 19.20 Bq/kg (mean value 8.44 Bq/kg). Analysis of ^{210}Pb accumulation in fish indicated that the accumulation was higher in bones than in muscle. Similar to the observation in molluscan shells and crustacean exoskeleton, the higher concentration is probably because of the tendency of lead to replace calcium. The present values of ^{210}Pb concentration in the muscle of fish are higher than those reported the muscle of Pike. (0.01 Bq/kg)[19] from Great Lakes of Alaska. Direct absorption of the radioisotope by the gill membrane could be a reason for this higher activity. In addition, the benthic mode of life and carnivorous feeding habit could also be considered since ingestion is the dominant means by which radioactive materials are accumulated in aquatic organisms.

Higher concentrations are seen in mollusca, crustaceans and fish. The order of the concentration factors reported here appear to agree well with the earlier observation of[11,20,6]. Concentration factors of ^{210}Po in comparison to ^{210}Pb in the same organisms were generally found to be less by an order of magnitude. This study provides a baseline data on the distribution of natural radionuclides ^{210}Po and ^{210}Pb in the Parangipettai coastal environment. ^{210}Po was greater degree in the soft tissue of animals while ^{210}Pb concentrated more in shell and bone. Present study provides sufficient evidence to suggest that the soft

tissues of green mussel *Perna viridis* accumulated higher concentration for both ^{210}Po and ^{210}Pb suggesting that this bivalve could serve as a bioindicator of radionuclides.

Results indicate the Parangipettai coastal environment is relatively a low background radiation region. Thus accumulation of these radionuclides by abiotic and biotic components of this region is at low level, compared to relatively high background radiation coasts such as Gulf of Mannar on the South and Kalpakkam coast on the North. It assumes greater significance because of the operation of Madras Atomic Power Station, Kalpakkam in the north east coast very close to this delicate ecosystem. Also a 2000 MW Nuclear Power Plant is being installed at Kudankulam in Gulf of Mannar and hence the generated data would be a valuable input for the assessment of changes in levels of radioactivity in the Parangipettai coast due to the operation of nuclear power plants in east coast of India.

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References

1 Cherry R D & Heyraud M, The Polonium-210 content of marine shrimp: Variation with biological and environmental factors. *Mar. Biol.*, 65 (1981) 165-175.

2 Skwarzec B & Falkowski L, Accumulation of Po-210 in Baltic invertebrates. *J. Environ. Radioactivity*, 8 (1988) 99-109.

3 Flynn W W, The determination of low levels of Polonium-210 in environmental materials. *Anal. Chim. Acta*., 43 (1968) 221-227.

4 Iyengar M A R, *Studies on the distribution of natural radioactivity in marine organisms.* Ph.D. Thesis, University of Bombay, Bombay, (1983).

5 Kamath P.R Bhat I S Kamala Rudran, Iyengar M A R Koshy E Waingankar U S & Khanolkar V S, Recent radiochemical procedures for bioassay studies at Trombay. *Proceedings of Symposium on Assessment of Radioactivity in man, Heidelberg, IAEA,* Vienna, (1964).

6 Sadiq Bukhari A Shahul Hameed M M Ravimankam T & Shahul Hameed P, Radiation Ecology of Palk Strait, *Journal of Radiation Protection and Environment* Vol. 26, (1-2), (2003) 473-477.

7 Masilamani V, Studies on the bioaccumulation of Polonium-210 and lead-210 in the biota of Gulf of mannar, India. Ph.D. thesis, Bharathidasan University, Tiruchirappalli. (2001).

8 Iyengar M A R, Kannan V, Ganapathy S & Kamath P R, Po-210 in the coastal waters of Kalpakkam. *Proceedings of the Second Special Symposium on Natural Radiation Environment, BARC,* Bombay, India, (1981).

9 Raja P & Shahul Hameed P, Bioaccumulation of Po-21 in Crustaceans, Molluscs and Fishes in the ecosystem of Pichavaram mangrove forest, Tamil Nadu, *J. Ecotoxicol. Environ. Monit.,* 18 (5) (2008) 451-456.

10 Somasundaram S S N, *Studies on the distribution and bioaccumulation of natural radionuclides in the ecosystem of Gulf of Mannar, India.* Ph.D Thesis, Bharathidasan University, Tiruchirappalli, India, (1998).

11 Iyengar M A R, Rajan M P, Ganapathy S & Kamath P R, Sources of Natural Radiation Exposure in a low monazite environment. Natural Radiation Environment III, Vol.2, *Proceedings of an International Symposium held at Houston, Texas,* USA, CONF-7804222, (1980).

12 Bangera V S & B.Patel, Natural radionuclides in sediment and in arcid clam (*Anadara granosa*.) & gobiid mudskipper (*Boleopthalmus boddaerti* Cuv. & Va.). *Indian J. Mar. Sc*. 13, (1984).

13 Lowman F G, Rice T R & Richards F A, Accumulation and redistribution of radionuclides by marine organisms; In " Radioactivity in the marine environment", a review document by committee on oceanography, *National academy of Sciences,* USA, (1971).

14 Pillai K C, *Heavy metals in aquatic environment*. (In C.K.Varshney (ed.), Water Pollution and Management, Wiley Eastern Limited, New Delhi), (1985) p. 75-93.

15 Shahul Hameed P, Somasundaram S S N, Shaheed K & Amanullah B, A Study on Polonium-210 Distribution in Abiotic and Biotic Components of Gulf of Mannar, India. *Proceedings of Fourth National Symposium on Environment*, Madras, India, (1995).

16 Shahul Hameed M M, *Studies on the distribution and bioaccumulation of Polonium-210 and Lead – 210 in the ecosystem of Palk Strait, India.* Ph.D Thesis, Bharathidasan University, Tiruchirappalli, India (2002).

17 FAO, *Species identification sheets for fishery purposes. Vol. II*, (Food and Agriculture organization of the United Nations, Rome) (1974).

18 Shahul Hameed P & Somasundaram S S N, *Radiation Ecology of Krusadai Island, Gulf of Mannar*, India. (Environmental Protection, Thukral. A.K and Virk. G.S. (Eds.), Scientific Publishers, Jodhpur, India), (2000) pp.192-197.

19 Holtzman R B, Natural levels of Lead-210, Polonium-210 and Radium 226 in humans and biota of the Arctic. Nature, 210 (1966) pp.1094-1097.

20 Skwarzec B, Accumulation of Po-210 in selected species of Baltic fish. *J. Environ. Radioactivity,* 8 (1988) 111-118.