Paper

DIETARY INTAKE OF ^{210}Po AND ^{210}Pb IN THE ENVIRONMENT OF GOA OF SOUTH-WEST COAST OF INDIA

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Abstract—**This paper deals with the distribution and activity intake of ^{210}Po and ^{210}Pb in food, diet, and potable water samples of the Goa region and the estimated committed effective dose due to ingestion of these radionuclides. The activity concentrations of ^{210}Po and ^{210}Pb were determined in about 30 food and diet samples from different places of Goa in order to know the distribution and intake of these radionuclides. The activity concentration of ^{210}Po in fish and prawn samples were significantly higher than concentrations found in vegetable and rice samples. Higher concentrations of ^{210}Po and ^{210}Pb were observed in leafy vegetables than in non-leafy vegetables. Among the diet samples the activity concentrations of ^{210}Po and ^{210}Pb in non-vegetarian meal samples were relatively higher than in vegetarian meal and breakfast samples. The committed effective dose due to annual intake of ^{210}Po was found to be 94.6 μSv, 49.1 μSv, 10.5 μSv, and 2.2 μSv and that of ^{210}Pb found to be 81.6 μSv, 59.9 μSv, 14.6 μSv, and 2.0 μSv for the ingestion of non-vegetarian meal, vegetarian meal, breakfast, and potable water, respectively.**
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Key words: diet; food chain; ^{210}Po; ^{210}Pb

INTRODUCTION

KNOWLEDGE OF the levels of radionuclides in dietary materials is important because these nuclides contribute a substantial portion of the radiation dose to humans (UNSCEAR 1972). A large contribution to the radiation dose received by human beings comes from naturally-occurring uranium series radionuclides accumulated in the body, namely ^{210}Pb, ^{210}Bi, and ^{210}Po (UNSCEAR 1982, 1993). The nuclides ^{210}Po ($t_{1/2}$ = 138.4 d) and ^{210}Pb ($t_{1/2}$ = 22.3 y) are the last radioactive members of the ^{238}U decay series. These are found widely in the environment mainly as a natural fallout from the decay of ^{222}Rn in the atmosphere and contribute about 8% of natural internal radiation dose to man (UNSCEAR 1988). These radionuclides are transferred to the human body through ingestion of food and potable water and cause internal exposure.

Various workers have studied the concentration of ^{210}Po and ^{210}Pb in a variety of foods which provide the main source of ^{210}Po and ^{210}Pb in human body (Jaworoswki 1969; Parfenov 1974; Holtzman 1980; Carvalho 1995). The assessment of ^{210}Pb in the human body is important because of the biological effect of its progeny activity, ^{210}Po. It has been reported that the radiation exposure to the body from ^{210}Po is greater than the exposure from ^{226}Ra and ^{90}Sr (Morse and Welford 1971). According to Parfenov (1974), ^{210}Po is of great radioecological interest because of its high toxicity and the fact that it contributes more than 30% total dose equivalent delivered to human tissues.

In view of these, concentrations of ^{210}Po and ^{210}Pb were measured in different foodstuffs and composite meals of Goa region and internal dose from intake of these radionuclides were estimated. The results are discussed in the light of values reported in the literature for other environs.

Detailed studies on distribution and intake of natural radionuclides have been carried out in the environment of Goa (Fig. 1). Goa is a small state situated at the west coast of India (14° 55′N, 74° 35′E to 15° 45′N, 74° 20′E) and is one of the most popular tourists centers in the country. It has an area of 3,700 km^2 sandwiched between the Arabian Sea and world famous western Ghats. The border of Goa state is just about 25 km from Kaiga, where the nuclear power plant of 235 MWe has started working recently and one more unit is in advanced stage of completion. Therefore, the present study has a special significance since it would help to assess the impact of a nuclear power plant and other existing mining industries on the dietary intake of ^{210}Po and ^{210}Pb in the environment. The study would also to shed light on the basic dynamics of the distribution and intake of radionuclides.

MATERIALS AND METHODS

Sample collection

Five towns, three from coastal cities and two from interior towns were selected for sample collections. The

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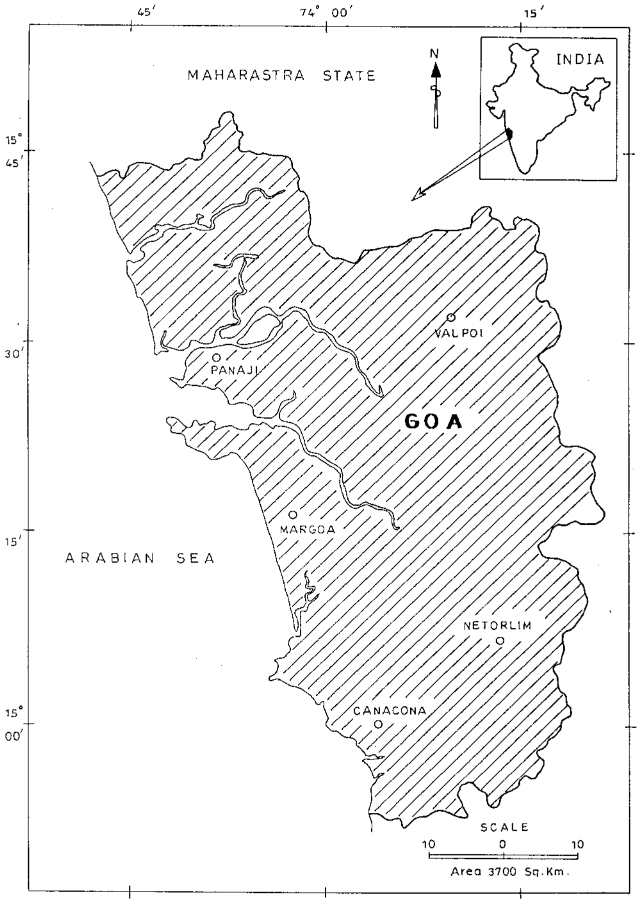

Fig. 1. Area covered under investigation and sampling stations of Goa State.

area covered under investigation and sampling stations are shown in Fig. 1. About 3–5 kg of food items such as rice and vegetables, which were grown in the region, were collected from market place. Fish and prawn samples were collected from fish market. Diet samples like veg, non-veg meal, and breakfast samples were collected from local hotels/restaurants. The major ingredient of non-vegetarian meal contains fish curry, rice, and curds and the vegetarian meal contains vegetable dhal, rice, and curds. The snacks "pav-baji" made from bread were collected for breakfast samples. About 40 L of the potable water were sampled from different origins, such as river, open well, bore well, and tap water, collected in a polythene Corby's. The food, diet, and potable water samples were collected during the period August–December 1999.

Analytical procedure

All the food and diet samples were brought to laboratory and oven-dried at 110°C (EML 1983; IAEA 1989). About 20–25 gm of dried sample was decomposed carefully by wet ashing with H_2O_2 and HNO_3 mixture followed by HCl. The residue was then dissolved in 0.5 M HCl with warming and a few milligrams of ascorbic acid were added to the solution and the solution was taken for electrochemical plating. Polonium was spontaneously deposited on brightly polished background counted silver disc and the activity was counted using ZnS(Ag) alpha counting system with an efficiency of 30% having background 0.3 cpm (Iyengar et al. 1990).

Water samples were filtered through Whatman 42 filter paper. ^{210}Po in water samples has been separated by co-precipitation of this radionuclide on $Fe(OH)_3$ by batch technique followed by electrochemical deposition on to a silver disc (Iyengar et al. 1982) and subsequently counted using ZnS(Ag) alpha counting system.

The recovery of ^{210}Po was determined by spiking ^{210}Po standard at the moment of digesting the samples by wet ashing. The average chemical recovery of ^{210}Po in this method was found to be 94%.

After ^{210}Po plating, the solution was stored about 6–12 mo to allow ^{210}Po ingrowth from the ^{210}Pb contained in the solution. The ^{210}Po grown from ^{210}Pb was once again replated and the activity counted using ZnS(Ag) alpha detector with a background of 0.3 cpm and an efficiency of 30% (Iyengar et al. 1990).

RESULTS AND DISCUSSION

^{210}Po and ^{210}Pb activity in food samples

The results of the activity concentration of ^{210}Po and ^{210}Pb in food and diet samples are given in Table 1. The activity range and mean values are given in the last two columns (7 & 8) of the same table. It can be seen from the table that leafy vegetables (spinach) show higher concentration than non-leafy vegetables (ribbed gourd). The marine food samples fish and prawn show a significantly higher level of ^{210}Po than rice samples. Among diet samples, non-vegetarian meal show relatively higher concentration than vegetarian meal and breakfast. Similar trends have also been observed for activity concentration of ^{210}Pb, as shown at the bottom of the same Table 1.

The results of the activity concentration of ^{210}Po in food samples are compared with the literature values reported for other environs and given in Table 2. It is evident from Table 2 that the mean activity concentration of ^{210}Po in vegetables (0.13 Bq kg^{-1}) is within the range reported for coastal Karnataka (Narayana et al. 1995a) and Kalpakkam (Rajan et al. 1987). The mean value is very low compared to the values reported for the Black Forest, Germany (Schuttelkopf and Kiefer 1982) and Argentina (Colangelo et al. 1992) and is very high compared to the values reported for Portugal environs (Carvalho 1995). The variation of activity concentration observed in vegetable samples from different places (Table 1) depends on accumulation of ^{210}Po on vegetables by atmospheric fallout and soil uptake. It is to be noted that the accumulation of ^{210}Po by vegetables depends on their morphological aspects and on plant age, soil type, chemical fertilizer, frequency of precipitation, and density of aerosols (Santos et al. 1990).

The activity concentrations of ^{210}Po in rice samples, having the range 0.13–0.49 Bq kg^{-1} with a mean value of

Table 1. ^{210}Po and ^{210}Pb concentration in food and diet samples in Goa.

Samples	Activity in Bq kg^{-1} (wet) ± standard deviation						
	Canacona	Margoa	Panaji	Valpoi	Netorlim	Range	Mean
			^{210}Po activity				
Food samples							
Ribbed gourd	BDL[a]	0.04 ± 0.02	0.02 ± 0.009	0.05 ± 0.02	0.08 ± 0.02	BDL–0.08	0.05
Spinach	0.09 ± 0.01	0.37 ± 0.05	0.13 ± 0.02	—	—	0.09–0.37	0.20
Rice	0.18 ± 0.11	0.21 ± 0.15	0.29 ± 0.16	0.13 ± 0.1	0.49 ± 0.17	0.13–0.49	0.26
Fish	1.74 ± 0.13	1.52 ± 0.16	1.55 ± 0.13	—	—	1.52–1.74	1.60
Prawn	7.78 ± 0.41	10.69 ± 0.44	10.48 ± 0.40	—	—	7.78–10.69	9.65
Diet samples							
Nonveg meal	0.17 ± 0.05	0.33 ± 0.06	0.21 ± 0.05	0.09 ± 0.05	0.12 ± 0.04	0.09–0.33	0.18
Veg meal	0.04 ± 0.02	0.08 ± 0.05	0.09 ± 0.03	0.08 ± 0.05	0.10 ± 0.05	0.04–0.10	0.08
Breakfast	0.16 ± 0.10	—	0.13 ± 0.08	0.07 ± 0.03	0.12 ± 0.07	0.07–0.16	0.12
			^{210}Pb activity				
Food samples							
Ribbed gourd	0.07 ± 0.01	0.06 ± 0.02	0.07 ± 0.02	0.16 ± 0.02	0.02 ± 0.01	0.02–1.42	0.38
Spinach	1.05 ± 0.03	0.20 ± 0.04	1.42 ± 0.04	—	—	0.2–1.42	0.89
Rice	0.27 ± 0.12	0.59 ± 0.17	0.91 ± 0.19	0.49 ± 0.10	0.55 ± 0.17	0.27–0.91	0.56
Fish	—	0.31 ± 0.07	0.16 ± 0.06	—	—	0.16–0.31	0.24
Prawn	0.51 ± 0.17	0.42 ± 0.11	—	—	—	0.42–0.51	0.47
Diet samples							
Nonveg meal	0.27 ± 0.07	0.23 ± 0.05	0.26 ± 0.06	0.13 ± 0.04	0.37 ± 0.06	0.13–0.37	0.25
Veg meal	0.24 ± 0.05	0.13 ± 0.04	0.18 ± 0.05	0.12 ± 0.04	0.17 ± 0.04	0.12–0.24	0.17
Breakfast	BDL	—	0.20 ± 0.08	0.38 ± 0.09	0.29 ± 0.10	BDL–0.38	0.29

[a] BDL—Below Detection Limit: If the net count of the sample is less than twice the square root of the standard deviation of the counter background, it is reported as BDL.

Table 2. Comparison of ^{210}Po in food samples with other environs.

Sample	Activity (Bq kg^{-1} wet)		Region	Reference
	Present work	Literature values		
Vegetables [8][a]	BDL–0.37 (0.13)[b]	BDL–0.14	coastal Karnataka	Narayana et al. (1995a)
		0.016–0.4	Mumbai	Khandekar (1977)
		BDL–0.2	Kalpakkam	Rajan et al. (1987)
		0.32	Argentina	Colangelo et al. (1992)
		0.054	Portugal	Carvalho (1995)
		0.33–1.63	Black Forest	Schuttelkopf and Kiefer (1982)
Rice [5]	0.13–0.49 (0.26)	BDL–0.20	coastal Karnataka	Narayana et al. (1995a)
		0.12	Mumbai	Khandekar (1977)
		0.1–0.5	Kalpakkam	Rajan et al. (1987)
		0.11	Argentina	Colangelo et al. (1992)
		0.23	Portugal	Carvalho (1995)
Fish [3]	1.52–1.74 (1.60)	1.84–5.08	coastal Karnataka	Narayana et al. (1995a)
		0.21–3.7	Mangalore region	Radhakrishna et al. (1996)
		0.98–24.6	Kalpakkam	Iyengar et al. (1980)
		1.8	Portugal	Carvalho (1995)
		0.6–26.0	Japan	Yamamoto et al. (1994)
		6	UK	Maul and O'Hara (1989)
Prawn [3]	7.78–10.69 (9.65)	12.38	Kalpakkam	Rajan et al. (1980)

[a] Value given in [ ] represents the number of samples analyzed.
[b] Value given in ( ) represents mean value; BDL—Below Detection Limit: If the net count of the sample is less than twice the square root of the standard deviation of the counter background, it is reported as BDL.

0.26 Bq kg^{-1}, are compared with the other environs given in Table 2. It can be seen from the table that the mean value is relatively high when compared to the environs of Mumbai (Khandekar 1977), Argentina (Colangelo et al. 1992), and Portugal (Carvalho 1995). However, the mean value is within the range reported for coastal Karnataka (Narayana et al. 1995a) and Kalpakkam environs (Rajan et al. 1987).

Table 2 shows that the marine food samples such as fish and prawn have a significant level of ^{210}Po activity. Higher levels of ^{210}Po concentration observed in marine species are expected due to the higher content of ^{210}Po in plankton. This is the main food for marine species present in sea water, which accumulates several kinds of radionuclides very rapidly, retains them for a long time, and leads to a considerable degree of selective concentration of the radionuclides from the sea water. Similar findings have been reported by several investigators (Parfenov 1974; Rajan et al. 1980; Iyengar et al. 1980;

Table 3. Comparison of ^{210}Pb in food samples with other environs.

Sample	Activity (Bq kg^{-1} wet)		Region	Reference
	Present work	literature values		
Vegetables [8][a]	0.02–1.42 (0.64)[b]	0.08–0.28	coastal Karnataka	Narayana et al. (1995a)
		0.12–1.65	Kalpakkam	Iyengar et al. (1979)
		0.11	Mumbai	Ramachandran and Mishra (1989)
		0.04	New York	Morse and Welford (1971)
		0.56–31.82	Black Forest	Schuttelkopf and Kiefer (1982)
		0.03	UK	Maul and O'Hara (1989)
		0.33	Portugal	Carvalho (1995)
Rice [5]	0.27–0.91 (0.56)	BDL–0.25	coastal Karnataka	Narayana et al. (1995a)
		0.14	Kalpakkam	Iyengar et al. (1980)
		0.03–0.48	Mumbai	Lalit et al. (1980)
		0.13	Mumbai	Ramachandran and Mishra (1989)
		0.27	Portugal	Carvalho (1995)
Fish [2]	0.16–0.31 (0.24)	0.50–1.33	coastal Karnataka	Narayana et al. (1995a)
		0.49–1.72	Mangalore region	Radhakrishna et al. (1996)
		BDL–0.75	Kalpakkam	Iyengar et al. (1980)
		0.13	New York	Morse and Welford (1971)
		0.04–0.54	Japan	Yamamoto et al. (1994)
		0.3	Portugal	Carvalho (1995)
		0.2	UK	Maul and O'Hara (1989)
Prawn [2]	0.42–0.51 (0.45)	0.23	Kalpakkam	Rajan et al. (1980)

[a] Value given in [ ] represents the number of samples analyzed.
[b] Value given in ( ) represents mean value; BDL—Below Detection Limit: If the net count of the sample is less than twice the square root of the standard deviation of the counter background, it is reported as BDL.

Maul and O'Hara 1989; Yamamoto et al. 1994; Carvalho 1995; Narayana et al. 1995a; Radhakrishna et al. 1996), and the values are given for comparison in Table 2.

The results of the activity concentration of ^{210}Pb in food samples are compared with the literature values reported for other environs and are given in Table 3. It can be seen from Table 3 that the mean value of activity concentrations of ^{210}Pb measured in vegetables are relatively higher when compared to the values reported for coastal Karnataka (Narayana et al. 1995a), Kalpakkam (Iyengar et al. 1979), and Mumbai environs (Ramachandran and Mishra 1989). The values are also higher when compared to the literature values reported for New York (Morse and Welford 1971) and UK (Maul and O'Hara 1989) and are comparable with the reported values for Portugal (Carvalho 1995). However, the activity concentration is very low when compared to the environs of the Black Forest, Germany (Schuttelkopf and Kiefer 1982).

The activity concentration of ^{210}Pb in rice samples, found to be in the range 0.27–0.91 Bq kg^{-1} with a mean value of 0.56 Bq kg^{-1}, is relatively high when compared to other environs (see Table 3).

It is interesting to note from Table 3 that the mean value of activity concentration of ^{210}Pb in vegetables is relatively higher than for the rice samples. It may be associated with larger surface area of leafy vegetables than paddy (grown rice), on which atmospheric ^{210}Pb deposits.

The mean values of ^{210}Pb activity in fish samples are compared with the literature values given in Table 3. It can be seen that the range and mean values are comparable with the reported values of all other environs (Morse and Welford 1971; Iyengar et al. 1980; Yamamoto et al. 1994; Carvalho 1995; Narayana et al. 1995a; Radhakrishna et al. 1996) and world average value (Maul and O'Hara 1989).

^{210}Po and ^{210}Pb activity in diet samples

Table 1 shows that the activity concentrations of ^{210}Po measured in non-vegetarian meals vary in the range 0.09–0.33 Bq kg^{-1} with a mean value of 0.18 Bq kg^{-1} and those of vegetarian meals vary from 0.04 Bq kg^{-1} to 0.10 Bq kg^{-1} with a mean value of 0.08 Bq kg^{-1}. Higher activity concentration observed in non-vegetarian meals is attributed to the ingredient of the non-vegetarian composite meal, which contains fish curry and rice. It is to be noted that fish samples show significant level of ^{210}Po activity. Rajan et al. (1987) have measured the ^{210}Po activity concentration in non-vegetarian and vegetarian meal samples and reported values of 0.97 Bq kg^{-1} and 0.35 Bq kg^{-1}, respectively.

It can also be seen from Table 1 that the activity concentration of ^{210}Pb measured in composite meals follows the same trend as observed in ^{210}Po activity. Lalit et al. (1980) have measured the ^{210}Pb activity in composite meal samples of the Mumbai region and the reported a value of 0.06 Bq kg^{-1}.

^{210}Po and ^{210}Pb activity in potable water

The results of ^{210}Po and ^{210}Pb concentration measured in potable water samples of different origin are presented in Table 4. The mean values are given at the bottom of the table. It can be seen from the table that the concentration of ^{210}Po and ^{210}Pb in bore well water (ground water) is significantly higher when compared to open well, tap, and stream water (surface water). The

Table 4. ^{210}Po and ^{210}Pb concentration in potable water samples.

Samples	Place	Activity in mBq L^{-1} ± S.D.	
		^{210}Po	^{210}Pb
Open well	Canacona	2.52 ± 0.34	5.36 ± 0.47
Bore well	Canacona	7.04 ± 0.54	11.48 ± 0.61
Tap water	Margoa	BDL[a]	—
Open well	Panaji	1.15 ± 0.24	2.37 ± 0.34
Tap water	Panaji	2.96 ± 1.89	0.86 ± 0.28
Open well	Valpoi	0.85 ± 0.23	0.46 ± 0.30
Tap water	Valpoi	1.55 ± 0.27	2.88 ± 0.45
Open well	Netorlim	2.14 ± 0.31	4.19 ± 0.41
Tap water	Netorlim	0.48 ± 0.15	2.83 ± 0.36
Stream	Netorlim	2.52 ± 0.33	2.98 ± 0.39
Mean			
Bore well		**7.04**	**11.48**
Open well		**1.66**	**3.10**
Tap water		**1.66**	**2.19**
Stream water		**2.52**	**2.98**

[a] BDL—Below Detection Limit: If the net count of the sample is less than twice the square root of the standard deviation of the counter background, it is reported as BDL.

Table 5. Daily intake and committed effective dose due to ^{210}Po and ^{210}Pb.

Samples analyzed	$[n]$[a]	Daily intake: fresh (in kg)	Daily intake: activity (Bq d^{-1})	CED (μSv y^{-1})
		^{210}Po Activity		
Diet				
Nonveg meal	[5]	1.20	0.216	94.6
Veg meal	[5]	1.40	0.112	49.1
Breakfast	[4]	0.20	0.024	10.5
Potable water				
Tap/Open well	[8]	3.0[b]	0.005	2.2
		^{210}Pb Activity		
Diet				
Nonveg meal	[5]	1.20	0.324	81.6
Veg meal	[5]	1.40	0.238	59.9
Breakfast	[4]	0.20	0.058	14.6
Potable water				
Tap/Open well	[7]	3.0[b]	0.007	2.0

[a] n = Number of samples analyzed [n].
[b] Volume of water in liters.

higher activity observed in bore well water of Canacona region may be due to the presence of granitic bedrock in these areas (GSI 1996). The lower activity of ^{210}Po and ^{210}Pb in surface water (i.e., openwell, tap, and stream) would be due to the lower amount of contact time that the water has with soil, compared to bore well water, which spends more time directly in contact with activity-bearing minerals. The mean values of open well water are comparable with the average value reported for Illinois (0.59 mBq L^{-1} for ^{210}Po; 1.89 mBq L^{-1} for ^{210}Pb; Holtzman 1964).

Daily intake of ^{210}Po and ^{210}Pb, and committed effective dose

Table 5 gives the daily intake of ^{210}Po and ^{210}Pb through non-veg meal, veg meal, breakfast, and potable water. The average consumption of non-vegetarian (1.2 kg) and vegetarian composite meals (1.4 kg) were calculated separately by taking two meals per day for each diet. The average consumption of one breakfast and potable water per day for each vegetarians and non-vegetarians are given in Table 5. The committed effective dose (CED) is estimated by multiplying the activity intake with the dose conversion factors for ^{210}Po (1.2 μSv Bq^{-1}, ICRP 1996; IAEA 1996) and ^{210}Pb (0.69 μSv Bq^{-1}, ICRP 1996; IAEA 1996). The daily intake activity and the CED due to annual intake are given in column 4 and 5, respectively (Table 5).

It can be seen from the Table 5 that the daily intake activities of ^{210}Po for non-vegetarian meal, vegetarian meal, and breakfast samples were found to be 0.216 Bq, 0.112 Bq, and 0.024 Bq, respectively, and that of ^{210}Pb found to be 0.324 Bq, 0.238 Bq, and 0.058 Bq, respectively. The dietary intake of ^{210}Po and ^{210}Pb by the population of Goa is compared with the reported values for other environs given in Table 6. It can be seen from the table that the daily intake of ^{210}Po and ^{210}Pb by the population of Goa is either comparable to or relatively higher than their counterparts in other countries.

The committed effective doses (CEDs) due to annual intake of ^{210}Po and ^{210}Pb were found to be 94.6 μSv, 49.1 μSv, and 10.5 μSv and that of 81.6 μSv, 59.9 μSv, and 14.6 μSv for non-vegetarian, vegetarian, and breakfast samples, respectively (column 5, Table 5). It can be seen from Table 5 that the non-vegetarian meal contributes higher dose due to ^{210}Po when compared to vegetarian meal and breakfast. The major component of non-veg meal samples collected are fish curry and rice. As discussed earlier, fish samples show a significant ^{210}Po concentration and higher dose in non-veg meal may be traced to the higher ^{210}Po in fish. It can be evident from Table 5 that the largest contribution of dose due to annual intake of ^{210}Po and ^{210}Pb appears to be in the range 11–95 μSv. By comparison, the potable water contribution is quite small (<3 μSv) and is an insignificant source of ^{210}Po and ^{210}Pb to human exposure. The total CEDs due to annual intake of ^{210}Po and ^{210}Pb were found to be 107.3 μSv and 61.8 μSv from ^{210}Po and 98.2 μSv and 76.5 μSv from ^{210}Pb, respectively, for non-vegetarian and vegetarian population of the region. These values are derived from daily dietary intake comprising breakfast, potable water, and either one non-vegetarian meal or one vegetarian meal.

Figs. 2a and 2b show the percentage contribution of committed effective dose from different dietary sources (Column 5, Table 5) due to ^{210}Po and ^{210}Pb. It is clear from Figs. 2a and 2b that among dietary samples the percentage contribution of CEDs due to non-vegetarian meals are higher than vegetarian meals and breakfast samples.

CONCLUSION

- Leafy vegetables show higher concentration of ^{210}Po and ^{210}Pb than non-leafy vegetables. Marine samples like fish and prawn show a significant level of ^{210}Po concentration when compared to other food items such as rice and vegetables. Non-vegetarian meal samples show relatively higher concentration of ^{210}Po and ^{210}Pb than vegetarian meal and breakfast samples, and the daily intake activity of ^{210}Po and ^{210}Pb in diet samples are found in the trend: breakfast $<<<$ veg meal $<<$ non-veg meal;

Table 6. Comparison of daily intake of ^{210}Po and ^{210}Pb with other environs.

Sample	Activity (Bq d^{-1}) Present work	literature values	Region	Reference
		^{210}Po activity		
Diet	0.216 (nonveg)	0.19 (nonveg)	coastal Karnataka	Narayana et al. (1995b)
	0.112 (veg)	0.08 (veg)	coastal Karnataka	Narayana et al. (1995b)
		0.06	Mumbai	Khandekar (1977)
		0.17	Germany	Gloebel et al. (1966)
		1.2	Portugal	Carvalho (1995)
		0.48–0.69	Japan	Yamamoto et al. (1994)
		0.05–0.06	USA	Holtzman (1980)
		0.1	New York (UN)	UNSCEAR (1982)
		2.55	Finland	Kauranen and Miettinen (1969)
Potable water	0.005	0.01	Washington (US)	Cothern and Lappenbusch (1986)
		^{210}Pb activity		
Diet	0.324 (nonveg)	0.22 (nonveg)	coastal Karnataka	Narayana et al. (1995b)
	0.238 (veg)	0.19 (veg)	coastal Karnataka	Narayana et al. (1995b)
		0.13	Mumbai	Lalit and Shukla (1982)
		0.17	Germany	Gloebel et al. (1966)
		0.32	Finland	Kauranen and Miettinen (1969)
		0.05	New York	Morse and Welford (1971)
		0.47	Portugal	Carvalho (1995)
		0.02–0.04	Japan	Yamamoto et al. (1994)
		0.05–0.06	USA	Holtzman (1980)
		0.1	New York (UN)	UNSCEAR (1982)
Potable water	0.007	0.008	Washington (US)	Cothern and Lappenbusch (1986)

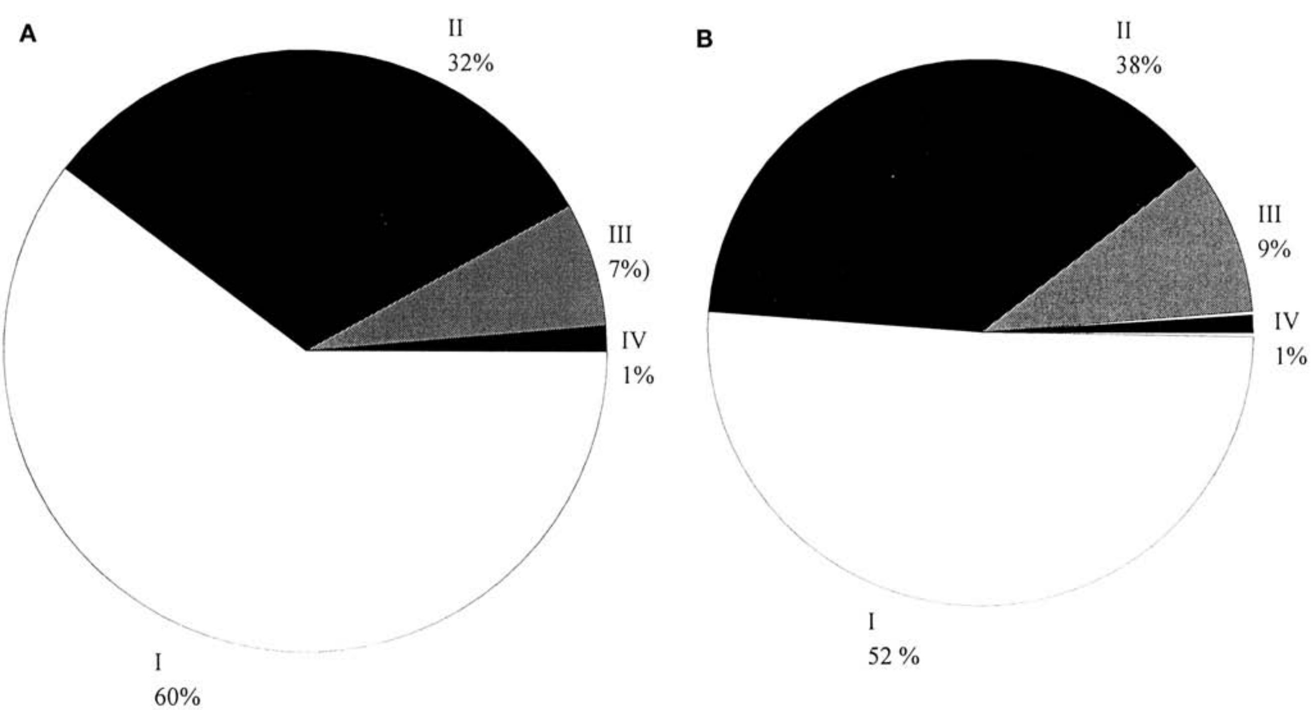

Fig. 2a. Percentage contribution of committed effective dose from dietary sources to ^{210}Po (I—Non-vegetarian meal, II—Vegetarian meal, III—Breakfast, IV—Potable water). **Fig. 2b.** Percentage contribution of committed effective dose from dietary sources to ^{210}Pb (I—Non-vegetarian meal, II—Vegetarian meal, III—Breakfast, IV—Potable water).

- Among potable water samples, higher activities of ^{210}Po and ^{210}Pb were observed to be higher in bore well than in open well and tap waters; and
- The committed effective doses due to the annual intake of ^{210}Po and ^{210}Pb for non-vegetarian and vegetarian population of Goa were found to be 107.3 μSv and 61.8 μSv from ^{210}Po and 98.2 μSv and 76.5 μSv from ^{210}Pb, respectively; and
- The CED due to the annual intake of potable water is negligible.

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