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Research Article

Potential health risk estimation of naturally occurring radionuclides intake due to the consumption of seafood around Coastal zone

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Abstract

As part of a regional baseline study, the distribution of naturally occurring radioactive materials in the marine fish diversity consumed by different age group representatives living in the Kalpakkam coastal zone was studied. The average activity of natural radionuclide in ^{238}U, ^{232}Th, and ^{40}K (n = 40) was 28.51, 239.58, and 118.95 Bq kg^{-1}, respectively. The annual dose of ingestion, lifetime carcinogenic risk assessment and cancer risk assessment due to ^{238}U, ^{232}Th, and ^{40}K were estimated by marine fish diversity in children aged 1-4,5-9,10-14,15-17 years, adults, pregnant women, and the fishing community. The Hospital-Based Cancer Registry (HBCR) compares to the coastal zone. Statistical studies such as Pearson correlation analysis, Principle component analysis, and Cluster analysis report check that the current levels of natural radionuclide do not pose a significant radioactivity threat to the residents based on the activity of the radionuclide.

Introduction

Fish production is important for global food security and trade because it accounts for more than 15% of all animal protein sources. International trade accounts for over 38% of worldwide fish production, with emerging countries accounting for around half of that (in terms of value). The global demand for seafood has spurred a spike in interest in the safety of fish as seafood sources [1]. Many countries have conducted studies on numerous types of contaminants in marine organisms to establish the safety of seafood [2].

External and internal radiation exposure in humans is mostly caused by naturally occurring radioisotopes. The most prevalent terrestrial radioisotopes that travel into the human body through food are the thorium and uranium series, as well as ^{40}K [3]. Uranium is one of the NORMS that can induce both radiotoxicity and element toxicity, whereas ^{232}Th is just radioactive toxic. Even though potassium is necessary for life, the isotope ^{40}K is radioactive toxic [4,5]. The ability of these radionuclides to gather in animal muscles as a result of food consumption poses a health risk [6].

Physical factors such as water and sediments and the accumulation and redistribution of radioactivity by marine fishes all influence the outcome of radioactivity transport [7]. Marine fishes feed on particles and debris, as well as larva fish, in sediments and under rocks [8]. Radionuclides that enter the human body through seafood can accumulate [9]. There has been little research on radioactive bioaccumulation in the maximum regularly ingested fish and crustacean species in the Bay of Bengal [10].

The study's major goal is to calculate the amounts of ^{238}U, ^{232}Th, and ^{40} K in seafood, which are thought to contribute the most to the internal dosage. The activity of ^{238}U, ^{232}Th, and ^{40} K was determined using an HPGe detector. The intake of dose and the corresponding committed effective dose, lifetime carcinogenic risk assessment, Computation of cancer risk assessment were estimated based on the distributed seafood, Prevalence of Cancer by Hospital Based Cancer Registry and statically studies were also evaluated using the determined by ^{238}U, ^{232}Th and ^{40} K concentration in the coastal zone.

Material and methods

Study area

The Kalpakkam Coastal stations (Sadras kuppam, Meyyar kuppam, Wyalli kuppam, Mahabalipuram beach, and Kokkilamedu kuppam) were chosen for their estimates of ^{238}U, ^{232}Th, and ^{40}K intake due to ingestion of seafood. Mahabalipuram Beach is one of the world's most renowned tourist destinations, famed for its seaside sculptures and temples. It is located 8 kilometers north of Madras Atomic Power Station (MAPS) (Latitude 120 62.093' N, Longitude 80019.878'E). Kokkilamedu station is located 5 kilometers north of MAPS (at latitude 120 59.342'N and longitude 80018.944' E), at the end of the Department of Atomic Energy (DAE) campus.

Meyyar kuppam (Lat 120 52.965' N, Long 80016.752' E) is a station. A community of fishermen was more in the Meyyar kuppam. Sadras kuppam is located 5 kilometers south of MAPS (Lat 120 52.363'N 80016.557' E) on the north side of the DAE municipality. Wyalli kuppam is located 8 kilometers south of MAPS (Lat 120 48.979'N 80015.876' E) in DAE Township. The seafood collected along the Kalpakkam coastal zone is shown in Figure 1.

Collection of fish samples

The seafood is collected around the kalpakkam coastal zone and kept in ice and transported to SRM Institute of Science and Technology for processing. Upon arrival at SRMIST, the fish samples were preserved in 10% formalin and the species identification was done at the Zoological Survey of India Laboratory (ZSI), Chennai. Each time 4 to 5 kg of the available seafood samples during the season caught by the fisherman were purchased. The fish were washed and only the consumption portions were collected and kept in ice boxes for further analysis of radionuclides.

Radioactivity analysis

The dehydrated seafood was ground into a powder and sieved a 200 mm for radionuclide analysis. A cylindrical radon airtight Polyvinyl chloride container with a distance of 6.5 cm and a depth of 7 cm was then used to hold a capacity of 100 cm^3 per sample. To prevent radon gas from escaping, containers were taped securely around the screw neck. To achieve equilibrium, samples were sealed for four weeks to match ^{222}Rn and ^{226}Rn.

Then, using the high purity germanium detector HPGe (EGPC-390-P21, with an active capacity of 390cc and a good aspect of 65 mm depth*21 mm dia), samples were exposed to gamma spectral research to compute activity. For the peak of 1332 keV of ^{60}Co, the sensor is an intrinsic coaxial higher resolution sensor with a resolution of 2.3 keV (FWHM). APTEC

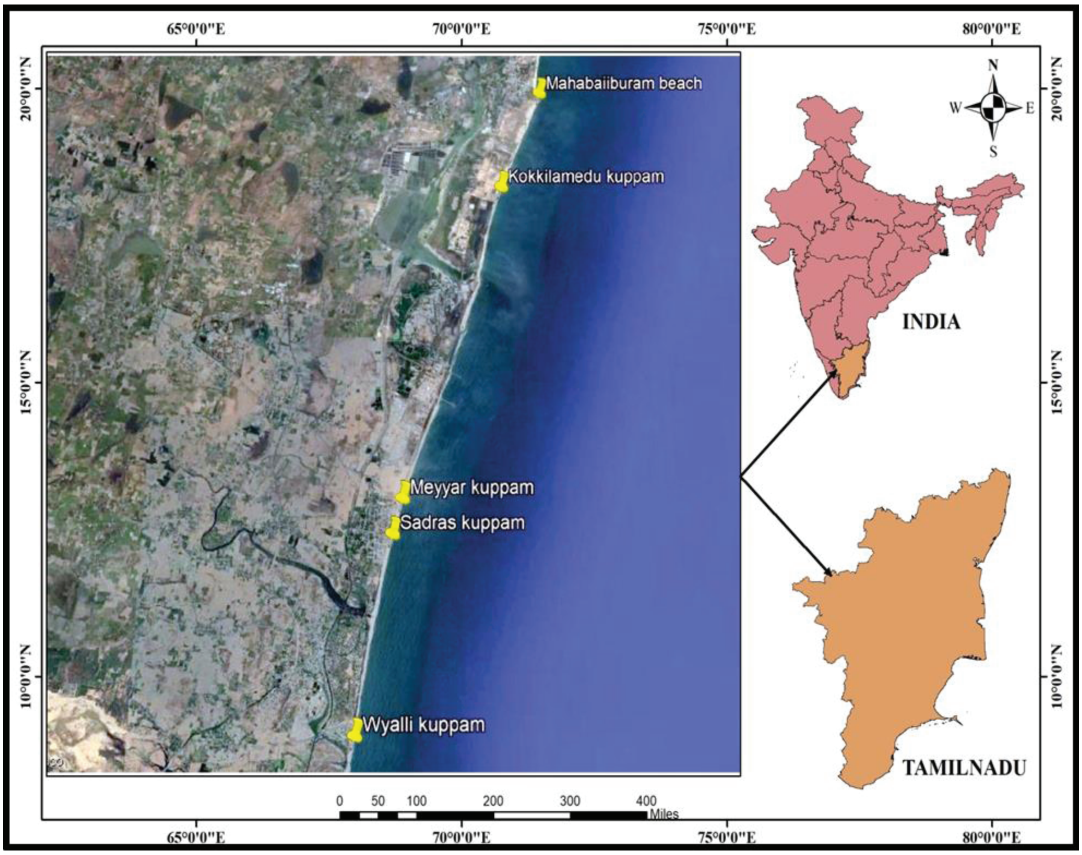

Figure 1: Shows the study area map.

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NRC software is used to determine the peak area and subtract the background. 1460.8 keV is used to calculate the activity of ^{40}K, and Bi is used to calculate the activity of (609.3keV).

Health risk assessment for carcinogenic and non-carcinogenic

Assessment of ingestion dose: The radioactivity in Bq kg^{-1} per day ingesting seafood was taken based on the fish diversity sample consumption data provided by National Nutritional Monitoring Board (NNMB) [11]. To calculate the consumption dose of the individual radioactivity as described the formula 1 described below was used.

$$D = Df * U * Cd$$

Where, the committed consumption dose (D). Df - factor of the coefficient. U - Yearly ingestion of the seafood (kg. y^{-1}). Concerning age groups, ingestion data for each seafood group was gathered from the NNMB, India. Cd - the average concentration (Bq kg^{-1}). The consumption dose of this radioactivity was assessed using dose exchange factors. The doses of intake were determined for the entire body [12].

Assessment of lifetime carcinogenic risk: The excess lifetime carcinogenic risk can be calculated by multiplying the Daily Dose on Average (ADD) by the Factor of Slope (SF) and the length of life (75.2 y). Slope factors are compared to the summary table [13]. The radionuclides risk exposure to different body parts. The U.S. Environmental Protection Agency (USEPA) radionuclides risk about 1 chance in 1,000,000 (1×10^{-6}) to be so minor as to be insignificant. And risks greater than 1×10^{-4} are large enough to need some form of remedy. Excess cancer risks ranging from 1×10^{-6} to 1×10^{-4} are generally regarded as reasonable [14]. The formula used in lifetime cancer risk.

$$Risk = ADD*Sfo*\text{ exposure duration}$$

Where, Hazard is the chance of developing cancer in a person's period that is less than one unit; ADD = Dosage for a Normal Day [mg/kg-day; pCi]; and Sfo is the slope factor, which is measured in [pCi/risk]. Since the USEPA's has as long as given slope factors (SFo) in unit concentration/hazard for ^{40}K (9.27027E-10), ^{238}U (2.34054E-09), and ^{232}Th (3.59459E-09), the risk has been linked to doses factor [15]. Because the slope factors are supplied in pCi/risk units, the activities must be translated from Bq to pCi. 1 Bq = 27 pCi is the conversion factor utilized.

Cancer Risk assessment from seafood: The cancer risk assessment of natural radionuclides was calculated using the Environmental Protection Agency's Guidelines [16], for ^{238}U, ^{232}Th, and ^{40}K. The equation was used to calculate the risk assessment for the ingestion pathway.

$$Cancer\ Risk = Sf \times I$$

Where, Slope Factor (Sf). The Slope Factor (Sf) for various natural radionuclides is discussed [16]. I am the predicted intake of any radionuclide using the equation

$$I = CF \times IR \times FI \times EF \times ED$$

Where, CF - radionuclide activity (Bq kg^{-1}), the intake amount (kg/d) is referred to as IR. FI is the proportion of food consumed from a contaminated source that is less than one unit - In the lack of more information; a conventional approach can take up that the portion consumed from a polluted source is 100% or 1%. [17], Depending on the age groups, EF - frequency of exposure (d/y) – 365 d/y and ED - duration of exposure (y).

Hospital-Based Cancer Registry (HBCR): The prevalence of cancer was investigated in this study using HBCR at the Cancer Institute (W.I.A), Chennai, which is closer to our research area. Since 2012, the Cancer Institute (W.I.A) in Chennai has established a cancer registry to collect data on morbidity cancer cases in our research area. This program gathers patient records from the international agency for research on cancer criteria for cancer epidemiological registration methods [18] and creates a database on cancer cases in a specific hospital.

Frequently, the register will receive records for a single patient from multiple sources, such as a hospital, a pathology lab, and a vital statistics office. All of these records must be linked to the same patient to ensure that each patient's information is complete and that no duplicate registrations for the same tumor are made. The connection is a key activity that cannot be overstated. The incidence report should include a definition and, if possible, a description of the registry's geographic coverage area.

The source of the population at risk should be adequately documented when information is included in the incidence report for subdivisions of the population, such as geographical regions within a country or ethnic groupings. This sort of study will provide the cancer prevalence rate in the study region for a set period for various types of cancers in the study region [19]. The cancer registry for our research region was collected based on this program over ten years from 2011 to 2020, collecting the total number of cancer cases for both males and females from the Hospital-Based Cancer Registry (HBCR) at Cancer Institute (W.I.A), Chennai. Using the equation, the Crude Cancer Incident Rate (CCIR) for the Kalpakkam coastal zone was calculated.

CCIR = [New cancer cases in a given year/estimated population in that same year] × 100000

The crude cancer incidence rate is calculated by multiplying the total amount of new cancer cases in the region by the entire number of people in the study region [20].

Statistical analysis

The origin 2018 program was used to statistically handle the data from the analytical operations. The current study used a multivariate analysis technique to investigate the link between seafood and radionuclides in the environment using the Pearson correlation matrix, principal component analysis, and cluster analysis.

Result and discussion

Radioactivity in seafood

Seafood is the major contributor to the radiation dose

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received by people through consumption. The radionuclide activities of fish in foodstuffs are much greater linked to other seafood sources in the food category, according to [21]. The importance of monitoring radioactive levels in seafood is increased (i) because they contribute significantly to the natural radiation dosage received by humans who consume them; and (ii) comprehending the seafood's radiological sensitivity. As a result, aquatic organisms such as seafood have become a biomarker in the monitoring of radionuclide pollution in the environment [22].

A total of 102 species of fish belonging to two groups, 22 orders, and 56 families were reported from the kalpakkam around the coast. Only 40 fish species are consumed predominately and available although out the seasons were analyzed for the radionuclides. This study was undertaken to evaluate the relationships between the ingestion, bioaccumulation, and distribution of potassium, uranium, and thorium in seafood. The activities of radionuclides ^{40}K, ^{238}U, and ^{232}Th in the seafood in different seasons are shown in Figure 2. The potassium activities in the marine fish's average concentration were 118.95 (Bq kg^{-1}). The range from 11.23 to 39.53 (Bq kg^{-1}) with minimum activity observed in *Upeneus targula* at southeast monsoon 2019 and maximum activity observed in *Filimanus heptadactyla* at southeast monsoon 2020.

Similarly, the uranium activities in the marine fish diversity average concentration was 28.51(Bq kg^{-1}). The range from 10.23 to 60.43 (Bq kg^{-1}) with minimum activity observed in *Charybdis feriatus* at northwest monsoon 2019 and maximum activity observed in *Penaeus monodon* in winter 2019. The thorium activities in the marine fish diversity average concentration was 239.58 (Bq kg^{-1}). The range from 18.91 to 916.49 (Bq kg^{-1}) with minimum activity observed in *Sepioteuthis lessoniana* at southeast monsoon 2020 and maximum activity observed in *Penaeus monodon* in winter 2019. Both naturally and intentionally generated radionuclides have been detected in the marine biota, according to [23,24].

The activities of radionuclides like potassium, uranium, and thorium in seafood samples were Below the Detection Limit (BDL) at the following seafood are shown in Table 1. (*Lutjanus vitta*, Scolopsis *vosmeri*, *Siganus canaliculatus*, *Rastrelliger kanagurta*, and *Sillago sihama*). A comparison of the present results with the work carried out by other researchers shows that the radionuclide activities observed during the present work are higher than previously reported values as indicated in Table 2.

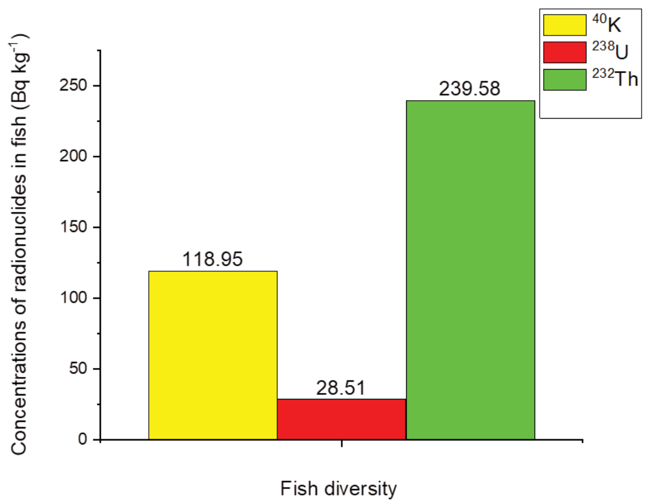

Figure 2: Distribution of the radionuclides in fish diversity.

Dose assessment

Natural radionuclides are created by radioactive materials in the earth's crust as well as natural radioactivity from deep space. As a result, they are always present in the surroundings and can be found in various activities in food. Intakes of radionuclides by swallowing can expose people to radiation. The public's natural radiation dosage is just approximately 2/3 of the worldwide average (2.4 mSv/y), according to the UNSCEAR 1993. Natural radiation sources are estimated to account for 98 % of the dosage absorbed by normal Indian people [30]. However, in industrialized countries, where radionuclides are widely employed for treatment purposes, the situation is different.

Human beings receive roughly 50% of their yearly radionuclides dose from natural background radioactivity, 2% from consumers, and 48% from medical, according to a recent study [31]. Carcinogen threats are assessed as individual groups for developing malignant cells during exposure [32]. The slope factor (SF) changes cancer risk based on lifetime exposure [33]. Also disused a fundamental estimate of Consumption and inhalation slope factors in the radioactivity threat per unit of concentration breathe in or swallowed conveyed as risk/pCi

Food consumption rate of seafood for different groups: The National Nutrition Monitoring Bureau (NNMB) reports were used to classify the age groups around Kalpakkam coastal zone and the food consumption rates for seafood intake [11]. According to the reports, the average intake of seafood for 1-4 years was 2 g per day, while for 5-9 years was 4 g per day, while for 10-14 years was 7 g per day, while for 15-17 years was 11 g per day, while for adult was12 g per day, while for pregnant women was 13 g per day, while for fisherman community was 12 g per day. The annual intake for the different age groups was calculated for kg/y as shown in Table 3.

Yearly effective dose due to consumption of seafood: Consumption of radioactivity through food accounts for a significant portion of typical radiation doses to many tissues of the body and is also an essential avenue for long-term health issues. The content of human diets varies by location and by individual. Because the majority of natural radionuclides entering the food chain come from the sediment, the difference in the sediment radionuclide concentration is a major source of topographical variation.

From Table 4 it was observed that the yearly effective dose is due to the consumption of fish via ^{40}K, ^{238}U, and ^{232}Th. It can be concluded that pregnant women are more proven to be at risk but that also less than I so safe due to the ingestion of fish caught around the Kalpakkam coastal zone. The annual effective dose via ^{40}K, ^{238}U, and ^{232}Th for age group 1-4 years ranged from 7.81E-05 to 3.62E-06, age group 5-9 years ranged from 1.21E-

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Table 1: Shows Fish diversity and association with radionuclides.

S. No.	Fish species	^{40}K (Bq kg^{-1})	^{238}U(Bq kg^{-1})	^{232}Th (Bq kg^{-1})
1	*Carangoides oblongus* (Cuvier, 1833)	183.92 ± 73.78	BDL	BDL
2	*Penaeus monodon* (Fabricius, 1798)	BDL	60.43 ± 17.77	916.49 ± 31.33
3	*Lutjanus vitta* (Quay & Gaimard, 1824)	BDL	BDL	BDL
4	*Nemipterus japonicus* (Bloch, 1791)	86.73 ± 65.46	BDL	BDL
5	*Leiognathus equulus* (Forsskal, 1775)	29.89 ± 7.86	BDL	BDL
6	*Thenus orientalis* (Lund, 1793)	BDL	30.85 ± 15.84	654.46 ± 27.71
7	*Plotosus lineatus* (Thunberg, 1787)	147.94 ± 66.77	BDL	107.74 ± 14.64
8	*Trachinocephalus myops* (Forster, 1801)	141.35 ± 75.29	BDL	63.16 ± 15.90
9	*Pomadasys maculatus* (Bloch, 1793)	166.92 ± 57.95	BDL	24.11 ± 11.61
10	*Monomia gladiator* (Fabricius, 1798)	164.89 ± 72.21	BDL	104.27 ± 15.82
11	*Scolopsis vosmeri* (Bloch, 1792)	BDL	BDL	BDL
12	*Upeneus targula* (Richardson, 1846)	11.23 ± 67.41	BDL	BDL
13	*Johnius elongatus* (Lalmohan, 1976)	75.72 ± 63.58	BDL	BDL
14	*Zebrias quagga*(Kaup, 1858)	133.14 ± 71.08	BDL	BDL
15	*Thryssa malabarica* (Bloch 1795)	22.92 ± 8	BDL	BDL
16	*Penaeus indicus* (H.Milne, 1837)	BDL	142.94 ± 21.84	156.13 ± 38.68
17	*Pempheris mangula* (Cuvier, 1829)	152.77 ± 69.2	BDL	127.69 ± 15.48
18	*Charybdis feriatus* (Linnaeus, 1758)	BDL	10.23 ± 12.91	346.11 ± 21.74
19	*Brevitrygon imbricata* (Bloch 1801)	150.54 ± 76.23	14.08 ± 11.14	209.93 ± 17.77
20	*Secutor insidiator* (Bloch, 1787)	183.05 ± 72.64	BDL	90.65 ± 15.45
21	*Siganus canaliculatus* (Park, 1797)	BDL	BDL	BDL
22	*Ablennes hians* (Valenciennes 1846)	180.67 ± 66.41	BDL	BDL
23	*Terapon jarbua* (Forsskål, 1775)	106.09 ± 68.95	BDL	BDL
24	*Mugil cephalus (Linnaeus, 1758)*	110.26 ± 62.06	BDL	BDL
25	*Sardinella longiceps* Valenciennes, 1847	22.93 ± 8.03	BDL	BDL
26	*Rastrelliger kanagurta* (Cuvier, 1816)	BDL	BDL	BDL
27	*Lepturacanthus savala* (Cuvier, 1829)	107.63 ± 65.37	BDL	51.33 ± 13.49
28	*Encrasicholina devisi* (Whitley, 1940)	126.65 ± 70.29	BDL	BDL
29	*Pseudorhombus triocellatus*(Bloch 1801)	108.93 ± 60.94	BDL	71.62 ± 12.93
30	Portunus sanguinolentus (Herbst, 1783)	173.98 ± 69.04	BDL	816.16 ± 14.69
31	*Thryssa mystax* (Bloch, 1801)	15.71 ± 7.68	BDL	BDL
32	*Arius africanus* (Günther, 1867)	126.19 ± 72.94	BDL	BDL
33	*Sillago sihama* (Forsskål, 1775)	BDL	BDL	BDL
34	*Sepioteuthis lessoniana* Férussac, 1831	89.84 ± 57.93	BDL	18.91 ± 11.69
35	*Filimanus heptadactyla (Cuvier, 1829)*	239.53 ± 75.51	BDL	BDL
36	*Charybdis natator* (Herbst, 1794)	BDL	30.21 ± 13.76	390.01 ± 22.75
37	*Pomadasys auritus* (Cuvier, 1830)	137.28 ± 63.32	BDL	BDL
38	*Epinephelus undulosus* (Quoy 1824)	111.58 ±	BDL	100.81 ± 1644
39	*Fenneropenaeus merguiensis* (de Man, 1888)	BDL	25.27 ± 12.10	248.31 ± 19.19
40	*Synaptura commersonnii* (Lacepede 1802)	117.33 ± 67.80	BDL	54.17 ± 14.19
	Mean	118.9517	28.51167	239.5821
	Standard Deviation	56.24555	17.77714	270.657
	Range	11.232 to 239.53	10.23 to 60.43	18.91to916.49

04 to 3.62E-06, age group 10-14 years ranged from 1.76E-04 to 3.92E-06, age group 15-17 years 2.39E-04 to3.60E-06, adult ranged from 2.40E-04 to 3.21E-06, pregnant women ranged from 2.59E-04 to3.47E-06, and fisherman community ranged from 2.40E-04 to 3.21E-06. The annual effective ingestion dose of 40K, 238U and 232Th is ranging from 3.92E-06 to 3.21E-06 mSv/y, 1.15E-04 to2.69E-05 mSv/y and 2.59E-04 to 7.81E-05 mSv/y.

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Lifetime cancer risk due to ingestion of seafood: When chronic radioactivity intake has neither a biological nor a radiological half-life, estimating lifelong cancer risk becomes more difficult. Following ingestion or inhalation, these radionuclides transmit doses over the rest of an individual's life, throughout which time the cancer threat per unit dose may change. The temporal component of dose distribution owing to inside radionuclide uptakes is addressed by taking part in the effective dosage due to consumption over the next 50 years, referred to as the committed effective dose [33].

Nuclear scientists must make every attempt to inform the public about the cancer risks associated with human nuclear undertakings. This is particularly true if erroneous estimates result in a considerable estimation of the cancer risk in children when compared to adults. The lifetime risk from overall exposure is calculated by adding the hazards from all radionuclides and routes, regardless of the body part. Excess cancer threats below around 1 chance in 1,000,000 ($1 * 10^{-6}$) are deliberated minimal by the US EPA, whereas risks above $1 * 10^{-4}$ are deemed large enough to warrant remediation [34]. Table 5 shows cancer risk due to ingestion of fish that intake of fish diversity has no substantial radioactivity impact on human health or cancer threat; hence fish taken in the Kalpakkam coastal zone are regarded as safe for public consumption.

Table 6 shows the total lifetime cancer risk due to ingestion of seafood's that the total lifetime cancer threat associated with fish-eating. Based on this, we can infer that, more effect for pregnant women, but also less than one so no major radiological impact on public health and cancer risk. Similarly, several researchers have documented the overall lifetime cancer risk associated with the radioactive consumption of a variety of seafood. Because long-lived radionuclides have neither a biological nor a radiological half-life, estimating cancer risk from their consumption is more difficult. These radionuclides delivered doses to people throughout their lives through consumption or inhalation, with the threat of cancer per unit dose fluctuating according to [35]. Patra, et al. [36] talked about it as well. Overall, it can be determined that consuming the fish diversity found along the Kalpakkam coast has no major radiological influence on public health or cancer risk, and seafood is regarded as safe for human consumption.

Computation of cancer risk assessment from seafood: The morbidity risk due to natural radionuclides intake is low, where the levels fall within the EPA risk limit [16]. Table 7 shows the computation of cancer risk assessment from fish that indicated that the natural radionuclides limit was higher for ^{232}Th, and the lower risk was observed for ^{40}K and ^{238}U. The adult, pregnant women, and fisherman community age group will be at higher risk compared to other age groups.

The risk observed for seafood is in the order 3.64E-04, 8.17E-04, 1.27E-03, 1.55E-03, 6.37E-03, 6.37E-03, and 6.37E-03 for 1-4, 5-9, 10-14, 15-17 years, adult, pregnant women, and fisherman community age groups. The highest risk was found in the age group of adults, pregnant women, and fisherman community in particularly ^{232}Th. [25] discussed the range of activity of uranium, thorium, and potassium in marine fish

Table 2: Lists the yearly effective dose reported by other researchers.

Location	Radionuclide activity (Bq kg^{-1})			
	^{40}K	^{238}U	^{232}Th	References
India	0.31 ± 0.05 to 1.67 ± 0.48	0.31 ± 0.05 to 1.19 ± 0.17	0.31 ± 0.05 to 1.67 ± 0.48	[25]
Bangladesh	265 ± 417 to 460 ± 310	9 ± 19 to 13 ± 14	8.5 ± 9.6 to 13 ± 17	[26]
China	41.2-111		0.064-0.19	[27]
Oman	38.57	0.14-2.66	0.06-4.68	[28]
UNSCEAR	34-170	0.03	10	[29]
	11.232 to 239.53	10.23 to 60.43	18.91to916.49	Present study

Table 3: Shows the food consumption rate of fish for different age groups (NNMB, 2012).

S.No	Age Group	Average intake (g/day)	Annual intake (kg/y)
1	1--4 years	2	0.73
2	5-9 years	4	1.46
3	10-14 years	7	2.55
4	15-17 years	11	4.01
5	Adult	12	4.38
6	Pregnant women	13	4.74
7	Fisherman community	12	4.38

Table 4: Shows the yearly effective dose due to ingestion of fish.

S.No	Age Group	^{40}K (Bq kg^{-1})	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
1	1--4 years	3.62E-06	2.69E-05	7.81E-05
2	5-9 years	3.62E-06	3.8E-05	1.21E-04
3	10-14 years	3.92E-06	6.52E-05	1.76E-04
4	15-17 years	3.6E-06	1.15E-04	2.39E-04
5	Adult	3.21E-06	6.49E-05	2.40E-04
6	Pregnant women	3.47E-06	7.02E-05	2.59E-04
7	Fisherman community	3.21E-06	6.49E-05	2.40E-04

Table 5: Shows cancer risk due to ingestion of fish.

S.No	Age Group	^{40}K (Bq kg^{-1})	^{238}U (Bq kg^{-1})	^{232}Th (Bq kg^{-1})
1	1--4 years	1.60E-04	1.53E-04	1.25E-03
2	5-9 years	3.60E-04	3.45E-04	2.81E-03
3	10-14 years	5.60E-04	5.36E-04	4.37E-03
4	15-17 years	6.80E-04	6.52E-04	5.30E-03
5	Adult	2.80E-03	2.68E-03	2.18E-02
6	Pregnant women	2.80E-03	2.68E-03	2.18E-02
7	Fisherman community	2.80E-03	2.68E-03	2.18E-02

Table 6: Shows the total lifetime cancer risk due to ingestion of fish.

S.No	Age Group	Total lifetime cancer risk through ingestion
1	1--4 years	5.21E-04
2	5-9 years	1.17E-03
3	10-14 years	1.82E-03
4	15-17 years	2.21E-03
5	Adult	9.09E-03
6	Pregnant women	9.09E-03
7	Fisherman community	9.09E-03

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Table 7: Shows the computation of cancer risk assessment from fish.

Radionuclides	Morbidity Risk from natural radionuclides via fish						
	1 year	5 years	10 years	15 years	adult	Pregnant women	Fisherman community
^{40}K (Bq kg^{-1})	1.11E-04	2.50E-04	3.89E-04	4.72E-04	1.94E-03	1.94E-03	1.94E-03
^{238}U (Bq kg^{-1})	1.07E-04	2.41E-04	3.74E-04	4.55E-04	1.87E-03	1.87E-03	1.87E-03
^{232} Th (Bqkg^{-1})	8.73E-04	1.96E-03	3.06E-03	3.71E-03	1.53E-02	1.53E-02	1.53E-02

samples from the Bay of Bengal, which has been reported. However, the estimated cancer risk assessment in our study for natural radionuclides via seafood does not possess any potential risk to the population residing around Kalpakkam coastal zone.

Prevalence of cancer by Hospital-Based Cancer Registry: In this study, the prevalence of cancer was surveyed by HBCR at Cancer Institute, Chennai, which is nearer to our study region. The cancer registry is maintained at Cancer Institute, Chennai since 2012 to collect information on morbidity cancer cases prevailing in our study region. According to census data of India in 2016 Kalpakkam had 94,968 inhabitants, of which 44,028 are male and 50,940 are female. Totally 4900 cancer incidence cases were identified from the Cancer Institute (W.I.A), Chennai for the period of 5 years 2012 to 2016. The total crude cancer incident rate in this area was 112.9.

Among the reported number of new cases by year of diagnosis cancer cases in 2012 (3894), 2013 (4081), 2014 (4587), 2015 (4799), 2016 (4900), 2017 (5271), 2018(5545), 2019(5817), and 2020 (6091) cancer recorded. A total of 4,900 new cancers, diagnosed in the year 2016 were registered. Almost two-thirds of cases were registered from hospitals located around Kalpakkam. A majority were either first diagnosed or registered for TNCR at the cancer institute (W.I.A) Chennai, followed by RGGGH, Chennai, Government Arignar Anna Memorials Cancer Hospitals, and government and non-government sectors together respectively [37].

From the HBCR records, among the reported cancer cases, 773 cases of breast i.e. 20.63 % are the highest cancer recorded. 203 cases of tongue (5.42 %), 228 cases of mouth (6.08%), 138 cases of oesophagus (3.6%), 345 cases of stomach (9.2 %),305 cases of large bowel (8.14 %),267 cases of lung (7.13 %),385 cases of cervix (10.27 %),149 cases of ovary (3.98 %),152 cases of lymphoma (4.06 %),135 cases of leukemia (3.6%),62 cases of oropharynx (1.65%),103 cases of hypopharynx (2.75%),98 cases of larynx (2.62%), 127 cases of corpus uteri (3.39%),121 cases of prostate (3.23%),510 cases of bladder (1.36 %), and 105 cases of brain & CNS (2.8 %), in 2016 year period. Vendhan Gajalakshmi et al 2001 [38] also discussed the epidemiology of the most common cancers in India.

In a review of cancer registration in India, Sahoo, et al. 2018 [39] discuss that HBCRs are useful in planning hospital facilities, assessing infrastructure, and assisting in hospital management to improve care, according to the current state and future issues. Planning and policymaking are aided by HBCRs.

Cancers of the lung, esophagus, and stomach in males, and breast and cervix uteri in women, are the most common cancers in India. They account for 39% of all malignancies. Tobacco-related malignancies (oral cavity, oropharynx, hypopharynx, esophagus, stomach, larynx, lung, pancreas, and urinary bladder) account for 48 percent of cancers in men and 19 percent in women. Compared to the reported cancer incidences by various authors on man-made, natural radionuclides, the prevalence of cancer cases observed around the Kalpakam coastal zone is low and no higher prevalence of cancer was observed due to natural background radiations in our study region, still, various factors like chemicals, smoking, drugs and other sources which may be the cause of cancer must be looked into it.

The pathogenesis of cancer production and the standard permissible limits of radionuclides: Carcinogenesis is thought to be a multistep process that requires two or more intracellular events to transform a normal cell into a cancer cell. Three main lines of evidence support the idea that carcinogenesis involves more than one step: (a) the rate of cancer mortality increases as a power function of age, and (b) a long latent period typically exists between exposure to a known carcinogen and the appearance of cancer, and (c) three distinct and separate stages have been identified in experimental carcinogenesis: initiation, promotion, and progression [40]. According to the standard permissible limits of radionuclides in different agencies Department of Food Safety Pharmaceutical & Food Safety Bureau Ministry of Health Labour and Welfare were 500 Bq kg^{-1}, World Health Organization were 350 Bq kg$^{-1,}$ and Food and Agriculture Organization750 Bq kg$^{-1.}$

Statistical studies

Pearson correlation analysis: The relationship between seafood variety and radioactive dispersion can provide insight into radionuclide pathway contamination sources. The high correlation coefficient between seafood and radionuclides demonstrates their shared nature, reciprocal dependency, and similar behavior during transportation. Through the calculation of the linear Pearson correlation coefficient, correlation analysis was performed as a bi-variation statistic to determine the reciprocal relationships and strength of the link between pairs of variables. Table 8 shows the Pearson correlation matrices for seafood radionuclides in the Kalpakkam coastal zone to determine correlations between the variables. Pearson correlation analysis is estimated using a two-tailed test of significance. Other radionuclides and the ^{40} K have a high association. Radionuclides ^{238}U and ^{232}Th had a negative correlation with other radionuclides, while radionuclides ^{238}U and ^{232}Th had a weaker positive association with other radionuclides.

Principle component analysis (PCA): The first principal component attempts to encompass as much variety in the statistics as feasible, whereas another is orthogonal to the first.

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Estimation of commonalities, eigenvalues or eigenvectors, and clarified total variance are all part of the PCA. The PCA will generate principle components (PC) for any given data structure, which are linear groupings of variables that account for the most modification within the data set by labeling vectors of closest fit to n explanations in p-dimensional space that are orthogonal to one added.

The results of PCA for total variance and component matrices seafood and radionuclides are listed in Table 9. According to these results, the seafood and radionuclides distribution could be grouped into three-component models, which accounted for 100 % of all of the data variation. These results coincided with the conclusion of the Eigenvalue correlation analysis. The first component (PC1) explained 52.51% of the overall difference with an eigenvalue of 1.57. This component could be identified as "^{40}K".

The additional component (PC2), with an eigenvalue of 0.84, explained 28.13 percent of the overall modification, while the third component (PC3), with an eigenvalue of 0.58, explained 19.36 percent of the total variance. "^{238}U and ^{232}Th" could be used to identify this component. Because the first and second principal components typically accounted for a large portion of the total variance, the first three Principal Components (PC1, PC2, and PC3) were plotted against each other, and sample clustering was possible in the effects of all variables within the three-dimensional planes, as shown in Figure 3. The quantity of fish diversity was connected with radionuclides, according to the findings.

Cluster analysis: When constructing clusters, the clustering approach takes into account the dissimilarities or distances between objects. The fish diversity and radionuclides distribution in each year were grouped. Based on Bray-Curtis similarities (log 1transformed) abundance data were subjected to cluster analysis using the complete linkage method. The results of cluster analysis for matrices of fish diversity and radionuclides distribution are shown in Figure 4. From the results of the cluster, it was possible to establish significant groups that showed maximum similarity. 23 individual clusters were obtained from cluster analysis based on the correlation coefficients distance of the parameters under investigation.

Table 8: Shows the Pearson correlation matrices for fish diversity and radionuclides in the Kalpakkam coastal zone.

	^{40}K	^{238}U	^{232}Th
^{40}K	1	-0.41184	-0.18468
^{238}U	-0.41184	1	0.38813
^{232}Th	-0.18468	0.38813	1

Table 9: Shows the results of PCA for total variance and component matrices fish diversity and radionuclides.

	Eigenvalue	Percentage of Variance	Cumulative	Coefficients of PC1	Coefficients of PC2
^{40}K	1.57521	52.51%	52.51%	-0.60766	0.44447
^{238}U	0.84391	28.13%	80.64%	0.63953	-0.21754
^{232}Th	0.58088	19.36%	100.00%	0.47091	0.86898

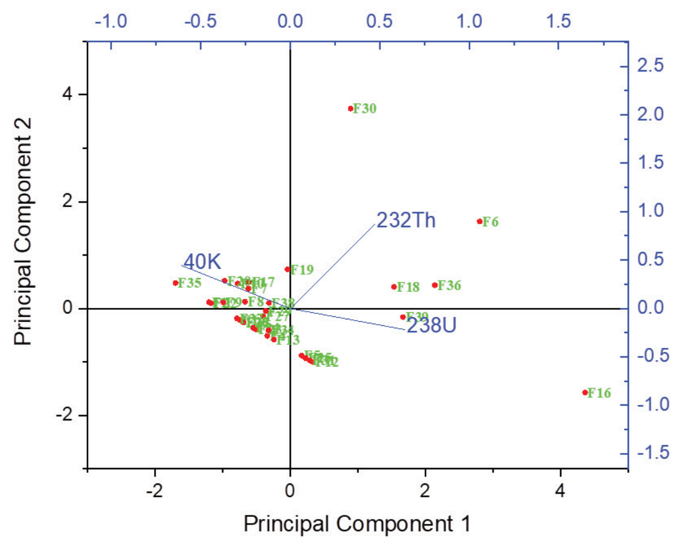

Figure 3: Showing Principle component analysis analysis of fish diversity and radionuclides distribution around coastal zone (F1) *Carangoides oblongus*, (F2) *Penaeus monodon*, (F4) *Nemipterus japonicas*,(F5) *Leiognathus equulus*, (F6) *Thenus orientalis*, (F7) *Plotosus lineatus* ,(F8) *Trachinocephalus myops*,(F9) *Pomadasys maculatus* ,(F10) *Monomia gladiator*, (F12) *Upeneus targula*,(F13) *Johnius elongatus*, (F14) *Zebrias quagga*, (F15) *Thryssa malabarica* , (F16) *Penaeus indicus*, (F17) *Pempheris mangula*, (F18) *Charybdis feriatus*, (F19) *Brevitrygon imbricate*, (F20) *Secutor insidiator* , (F22) *Ablennes hians*, (F23) *Terapon jarbua*, (F24) *Mugil cephalus*, (F25) *Sardinella longiceps*, (F27) *Lepturacanthus savala*, (F28) *Encrasicholina devisi*, (F29) *Pseudorhombus triocellatus*, (F30) *Portunus sanguinolentus*, (F31) *Thryssa mystax*, (F32) *Arius africanus*, (F34) *Sepioteuthis lessoniana*, (F35) *Filimanus heptadactyla* ,(F36) *Charybdis natator*, (F37) *Pomadasys auritus*, (F38) *Epinephelus undulosus* ,(F39) *Fenneropenaeus merguiensis*, (F40) *Synaptura commersonnii*.

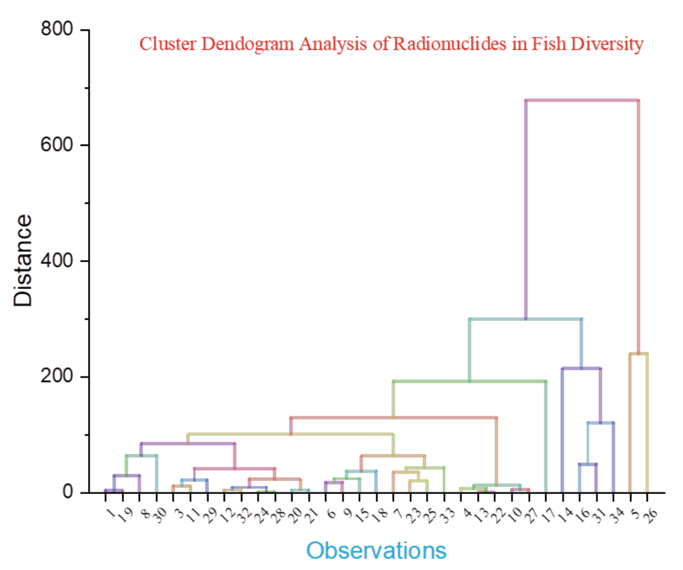

Figure 4: Shows cluster dendogram analysis of fish diversity and radionuclides distribution around the coastal zone (1) *Carangoides oblongus*, (2) *Penaeus monodon*, (4) *Nemipterus japonicas*,(5) *Leiognathus equulus*, (6) *Thenus orientalis*, (7) *Plotosus lineatus*,(8) *Trachinocephalus myops*,(9) *Pomadasys maculatus*,(10) *Monomia gladiator*, (12) *Upeneus targula*,(13) *Johnius elongatus*, (14) *Zebrias quagga*, (15) *Thryssa malabarica*, (16) *Penaeus indicus*, (17) *Pempheris mangula*, (18) *Charybdis feriatus*, (19) *Brevitrygon imbricate*, (20) *Secutor insidiator*, (22) *Ablennes hians*, (23) *Terapon jarbua*, (24) *Mugil cephalus*, (25) *Sardinella longiceps*, (27) *Lepturacanthus savala*, (28) *Encrasicholina devisi*, (29) *Pseudorhombus triocellatus*, (30) *Portunus sanguinolentus*, (31) *Thryssa mystax*, (32) *Arius africanus*, (34) *Sepioteuthis lessoniana*, (35) *Filimanus heptadactyla*,(36) *Charybdis natator*, (37) *Pomadasys auritus*, (38) *Epinephelus undulosus*,(39) *Fenneropenaeus merguiensis*, (40) *Synaptura commersonnii*.

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The cluster group1 appears at a distance level higher than 700 m and is associated with all the seafood ((1) *Carangoides oblongus*, (2) *Penaeus monodon*, (4) *Nemipterus japonicas*,(5) *Leiognathus equulus*, (6) *Thenus orientalis*, (7) *Plotosus lineatus*,(8) *Trachinocephalus myops*,(9) *Pomadasys maculatus*,(10) *Monomia gladiator*, (12) *Upeneus targula*,(13) *Johnius elongatus*, (14) *Zebrias quagga*, (15) *Thryssa malabarica*, (16) *Penaeus indicus*, (17) *Pempheris mangula*, (18) *Charybdis feriatus*, (19) *Brevitrygon imbricate*, (20) *Secutor insidiator*, (22) *Ablennes hians*, (23) *Terapon jarbua*, (24) *Mugil cephalus*, (25) *Sardinella longiceps*, (27) *Lepturacanthus savala*, (28) *Encrasicholina devisi*, (29) *Pseudorhombus triocellatus*, (30) *Portunus sanguinolentus*, (31) *Thryssa mystax*, (32) *Arius africanus*, (34) *Sepioteuthis lessoniana*, (35) *Filimanus heptadactyla*,(36) *Charybdis natator*, (37) *Pomadasys auritus*, (38) *Epinephelus undulosus*,(39) *Fenneropenaeus merguiensis*, (40) *Synaptura commersonnii*.)

This association is probably affected by the diurnal fluctuation pattern of these parameters with the intensity implying pollution from both natural and anthropogenic sources. Cluster group 2 appears at a distance level higher than 300 m and 17 major groups are associated with seafood. And cluster group 3 appears at a distance of 200 m and 14 major groups associated radionuclides with seafood. This association is probably based on the distance levels between the parameters and fish diversity under investigation, it is possible to identify the problematic parameters that affect the environmental situation around Kalpakkam coastal zone.

Conclusion

The distribution of NORM in several seafood resources is studied by the different age group representatives living in around Kalpakkam coastal zone to ensure the guidelines of the World Health Organization (WHO) in evaluating the pollutants in the seafood. This would serve as a baseline study for the coastal zone of Kalpakkam. Correspondingly, the annual intake and consumption dose, lifetime carcinogenic risk assessment, and cancer risk assessment were BDL in the seafood approach. According to the current research, the calculated ingested dose values for seven distinct age groups are well below the ICRP limit, indicating that there is no significant radiological threat to humans in this region.

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Declaration of conflict interests

All the authors agree with the contents and to the submission and disclose that there is no conflict of interest including financial, personal, or other relationships with other people or organizations.

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