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Applied Hypothetical Scenarios to Estimate the Human Risk of U-238 in *Leiognathus* sp. and *Portunus sanguinolentus* from Madras Nuclear Power Plant Zone, India

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ABSTRACT

The present investigation was set as a database study which estimated the bioaccumulation and potential human health risks of Uranium 238 (U-238) when consuming *Leiognathus* sp. and *Portunus sanguinolentus* from the Madras Atomic Power Station (MAPS) zone, India. In the study, two hypothetical scenarios were applied about the consumption of those fish and crab, calculating the values of some important pollution and human risk assessment indices, such as enrichment factor, bioaccumulation factor, estimated daily intake, daily intake of radioactivity, committed effective dose, lifetime cancer risk hazard, and risk quotient. The results showed that the study area has a moderate enrichment of U-238 (2< EF <5) during all seasons; furthermore, *Leiognathus* sp. and *P. sanguinolentus* are a hyper-accumulator (BAF>10.0) from seawater. The finding of this study demonstrates that, in light of the hypothetical 1st and 2nd scenarios, the index values are below the limit set, hence there is no radiation/chemical risk from the consumption of *Leiognathus* sp. and *P. sanguinolentus* as a dominant diet from the study area.

INTRODUCTION

U-238 is one of the naturally occurring radioactive elements due to their length of half-lives, which have the potential to be radioactive and chemically toxic for humans. Uranium goes a considerable distance from its source to the human diet via various routes in the ocean. It is introduced into the marine environment through anthropogenic activities, such as nuclear power plant operation, nuclear fuel processing, processing of mines and milling, agricultural activities, as well as oil and gas offshore exploration **(Khan *et al.*, 2011; Khandaker *et al.*, 2013)**. Furthermore, the natural activities, such as underwater volcanic eruptions, weathering of terrestrial rocks, seafloor movement caused by earthquakes and metrological and oceanographic phenomena contribute to its presence **(Abbasisiar *et al*., 2004; Al-Sharif *et al*., 2023)**.

Since uranium is quite soluble in seawater, it can be transmitted there through dissolving, attaching to plankton and seabed sediment, as well as contaminating marine organisms **(Carvalho *et al*., 2011)** which a human being might consume. Following oral exposure, < 0.1– 6% of the uranium is absorbed, most (> 98 %) of this amount is introduced into the gastrointestinal tract and subsequently excreted with feces **(Leggett & Harrison, 1995)**, while the absorbed uranium is distributed to bone and kidney then accumulates there. The risk of morbidity from that consumption is minimal when it is below the EPA risk limit; however, when it is beyond that level, it becomes chemically toxic and damages kidney tubular cells or other possible targets of toxicity such as the reproductive system. Besides that, the effects of radiation described by **Hutchinson (1966)** as "A widely accepted dogma in the field of radiation biology is that DNA is the most important molecular target of radiation because of its critical role in cell replication and proliferation, unrepaired DNA damage can lead to mutations, genomic instability, and cell death". While beef liver and kidneys, cow's milk, and root vegetables contain the highest levels of uranium in food, numerous governmental and international organizations, including the International Commission on Radiological Protection (ICRP), the World Health Organization (WHO), International Atomic Energy Agency (IAEA), have taken significant steps to ensure the safety of seafood.

In light of the aforementioned factors and the paucity of information on radioactive bioaccumulation in the most commonly consumed seafood species in the Bay of Bengal **(Biswas *et al*., 2021; Pandion & Arunachalam, 2022)**, this investigation aimed to assess the bioaccumulation and potential human health risks of U-238 in commercially important fish *Leiognathus* sp. and crab *Portunus sanguinolentus* from surrounding the Madras Atomic Power Station (MAPS) on the eastern coast of the Bay of Bengal. The study was designed as part of a regional baseline study dependent on the seasonal concentrations of U-238 in sediment, seawater fish and crab from **Al-Sharif *et al.* (2023)** investigation. The study applied two hypothetical scenarios of fish /crab ingestions to estimate the values of some important indexes, such as enrichment factor (EF), bioaccumulation factor (BAF), estimated daily intake (EDI), daily intake of radioactivities (DI), committed effective dose (CEF), lifetime cancer risk hazard (LCR), and risk quotient (RQ), since there may be concerns due to U-238 entering the human diet through the ingestion of marine products in the long term **(Khandaker *et al*., 2015)**.

MATERIALS AND METHODS

1. Study area

The current investigation was carried out on the eastern coast of the Bay of Bengal, specifically the area surrounding the Madras Atomic Power Station (MAPS), which is positioned on the beaches of Mahabalipuram and Kalpakkam. It is located 80 kilometers south of Chennai (Madras) the capital city of Tamil Nadu state in India (Fig. 1). As a result of the climate of India, which is greatly influenced by monsoon wind, as well as its implications on the seasonality of rainfall, the study was conducted in three different seasons: Post-Monsoon 2020 (PoMon), Pre-Monsoon 2020 (PrMon), and Monsoon 2021 (Mon).

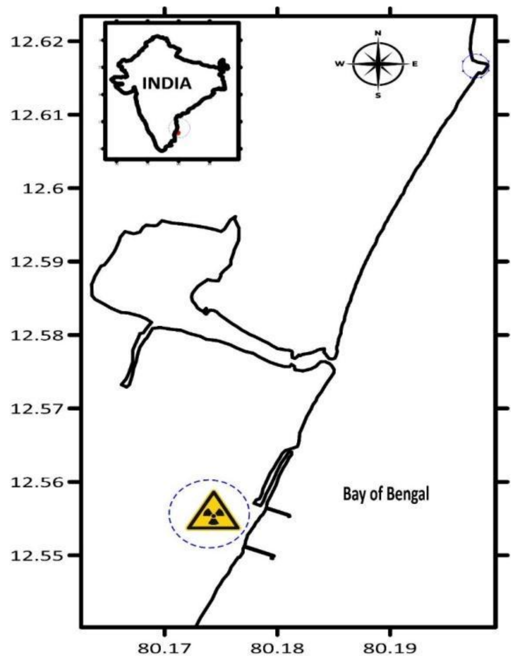

Fig. 1. Study area around MAPS

2. Assessment of U-238 concentrations/ radioactivity in sediments, seawater, and organisms

The concentrations of U-238 (ppb) in sediments (U SE), seawater (U Sw), fish (U F), and crab (U C) were obtained from **AL-Sharif *et al.* (2023)** study, and the concentrations of U-238 have been converted into Bq/ kg via the conversion factor 1ppm = 12.35 Bq/ kg, following the method indicated by **IAEA (1989)** and **Joel *et al.* (2018)**.

3. Environmental and radiological hazardous indices

Enrichment factor (EF), bioaccumulation factor (BAF), estimated daily intake (EDI), daily intake of radioactivities (DI), committed effective dose (CEF), lifetime cancer risk hazard (LCR), and risk quotient (RQ) were estimated in this investigation depending on different scenarios for achieving the goals of the assessment of ecological and human health hazards. Based on hypothetical scenarios, this study was designed with the understanding that the majority of these indices attempt to assess/estimate the consumption/effect of radionuclides on human health. Seasonal concentrations of U-238 in ppb or Bq/ kg in the sediment, seawater, fish, and crab samples. Seasonal concentrations were used instead of the annual concentration determined in the equations of those indexes to get more reflections about the behavior of those seasonal values.

The first scenario (1^{st}) is specific, we have applied the specific consumption of the target fish and crab according to the data from the annual report of **Fisheries statistic division (2022)**, which noted that the annual production of the Leiognathidae and Brachyura in India during 20-2021 are 57×10^6 and 61×10^6 tons, while in Tamil Nadu, they are 27×10^6 and 23×10^6 tons, furthermore the non-veg population is 6713×10^5 and 72477405 individual in India and Tamil nude, respectively **(Uidai, 2020)**.

On the other hand, the second scenario (2^{nd}) considered the annual consumption of 20-2021 (the investigation period) of fish as general by the Indian people is 6.31 per capita/ kg and by Tamilar is 9.3 per capita/ kg. Both scenarios aimed to reflect the true intake values of U-238 by the individual and gave us more factual possibilities about the risks. Furthermore, the investigation just dealt with the none veg adult Indian/Tamilar in the age group of 70 years **(Shyam *et al.*, 2013; Khandaker *et al.*, 2015; Uidai, 2020)**.

3.1 Enrichment factor (EF)

EF index is a normalisation technique used to assess the presence and intensity of element deposition on sediment with respect to a reference metal that is either *Fe* or Al, following the method of **Helz and Sinex (1981)** and **Rule (1986)**.

The EF was calculated by the following equation:

$$EF = \frac{(Cx\,Sample/CxRE)}{\left(\frac{Cx}{CxRE}\right)Background} \qquad (1)$$

Where, Cx and CxRE are the sediment's respective U-238 and Fe-56 levels (ppb). According to **Barbieri (2016)**, EF is classified as deficiency to minimal enrichment EF< 2, moderate enrichment 2< EF< 5, significant enrichment 5< EF<20, very high enrichment 20< EF< 40, and extremely high enrichment EF> 40.

3.2 Bioaccumulation factor (BAF)

The concentrations of radionuclides in organisms resulting from uptake from all exposure routes are commonly obtained utilizing bioaccumulation factors (BAF), which describe the internal concentration relative to an external concentration **(Karlsson *et al.*, 2002)**.

BAF was calculated using the following equations:

$$BAF = \frac{Cx\,Organism}{Cx\,Sediment} \qquad (2)$$

$$BAF = \frac{Cx\,Organism}{Cx\,Seawater} \qquad (3)$$

Where, Cx is the concentration of the U-238/ ppb in the sample. The BAF values are characterized as excluder (< 1.0), accumulator (1.0- 10.0), and hyperaccumulator (> 10.0), according to the guidelines of **Zhao *et al.* (2012)**.

3.3 Estimated daily intake of U-238 (EDI) (ppb/ day)

The health risk posed to consumers was determined by the specific dietary intake of each contaminant and compared with toxicologically acceptable levels. The daily intake of the U-238/ ppb from the consumption of fish/crab was estimated using equation (4), which was also used in similar studies by other researchers **Chiara (2013)** and **Bamuwamy *et al.* (2015)**, as follows:

$$EDI = \frac{Cx * Cr}{BW} \quad (4)$$

Where, Cx is the concentration of the U-238/ ppb in fish/crab, Cr is the consumption rate of the individual according to the 1^{st}/ 2^{nd} scenarios, and BW is the body weight of adult 70kg.

3.4 Daily intake of radioactivity of U-238 (Di) (Bq/ day)

The daily intake of radioactivity is determined by both the U-238 radioactive level and the amount consumed. Di was estimated using equation (5), which was employed by other researchers in comparable experiments, such as those of **Khandaker *et al.* (2015)**, as follows:

$$Di = \frac{Cx*AP*Fc}{Ap*365} \quad (5)$$

Where, Cx is the radioactivity of U-238 in fish/crab (Bq /kg), AP is the annual production according to the **Fisheries statistic division (2022)**, Fc is the real fraction consumed (68% of the production after a consideration of 32% wastage) **(UNSCEAR, 2000)**, and Ap is the Indian / Tamil Nadu non-veg population at 20-2021 **(Uidai, 2020)**.

3.5 Committed dose from annual intakes (CD)

The committed effective dosage to an adult from consumption of U-238 through fish/crab has been calculated using the formula below, according the outlines of **Ghose *et al.* (2000)**, **Khandaker *et al*. (2015)** and **Kazoka *et al.* (2023)**, as follows:

$$CD = Cx * Cr * Dcf \quad (6)$$

Where, CD is the annual effective dose to an individual (μSv /yr), Cx is the activity of radionuclides of fish/crab (Bq/ kg), Cr is the consumption rate of the individual according to the 1^{st} /2^{nd} scenarios, and Dcf is the ingestion dose conversion factor (2.8×10^{-7} Sv/ Bq for U-238 **(Fasae & Isinkaye, 2018)**.

3.6 Lifetime cancer risk (LCR)

The lifetime cancer risk is the probability that an individual would acquire cancer over their lifetime as a result of a certain concentration of a pollutant. Carcinogenic risk (LCR) was calculated using the method provided by the **USEPA, (1996)**, as follows:

$$LCR = Cx * ASL * Rc \quad (7)$$

Where, Cx is the annual intake of radionuclide (Bq); ASL is the average span of life (70y), and Rc is the mortality risk coefficient (Bq^{-1}). The cancer risk coefficient (Rc) of U-238 is 1.13×10^{-9} Bq^{-1} for mortality, according to outlines of **USEPA (1999)** and **UNSCEAR (2000)**.

3.7 Risk quotient (RQ)

In the deterministic approach, a risk quotient (RQ) is calculated by dividing a point estimate of exposure by a point estimate of effects. This ratio is a simple, screening-level estimate that identifies high- or low-risk situations. non-carcinogenic risk (RQ) and it has been calculated using the formula below:

$$RQ = \frac{Cx}{T} \quad (8)$$

Where, Cx is the exposure concentration of U-238 (ppb), and T is the toxicity refers to an effect level or endpoint obtained from eco-toxicity testing, such as a lethal dose (LD50) or no observed effect concentration (NOEC) **(USEPA, 2006)**. According to **Kathryn and Burklin (2008)**, the acute oral LD50 of uranium for humans is 5g.

RESULTS AND DISCUSSION

1. Enrichment factor (EF)

The EF is an indicator used to assess the presence and intensity of contaminant deposition in any ecosystem. In most seawaters, sediments are considered a sink for uranium, and the concentrations of uranium in sediments and suspended solids are several orders of magnitude higher than in the surrounding water **(Swanson, 1985; Brunskill & Wilkinson, 1987)**. The seasonal pattern of EF of U-238 in the sediment of the investigation site is presented in Fig. (2). The values indicate that U-238 exhibits moderate enrichment, according to **Barbieri (2016)** (2 < EF < 5, which corresponds to moderate enrichment), across all seasons. That seasonal variation in the U-238, as discussed by **Al-Sharif *et al.* (2023),** may be related to the coastal morphology and processes [longshore/cross-shore movement and sea current direction (SE/SW)]. This observation aligns with the findings of **Klerks and Levinton (1989)**.

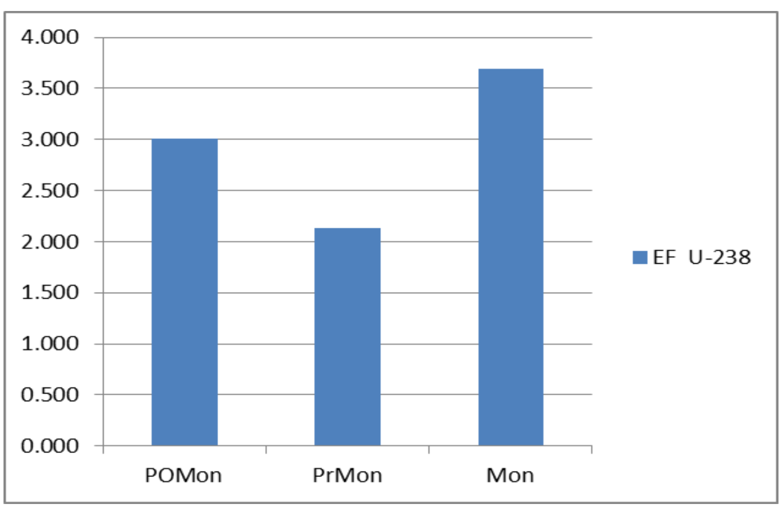

Fig. 2. Blot bar showing the EF values of U-238 during different seasons at MAPS

2. Bioaccumulation factor (BAF)

Bioaccumulation is the result of the uptake and retention of elements in organisms through complex mechanisms. The BAF values of this study showed the results of taking U-238 from the surrounding environment (sediment and seawater) by two important organisms in the marine food web (fish and crab). Although the concentrations of U-238 in the organisms, sediment, and seawater in **Al-Sharif *et al.* (2023)** study were particular and only altered seasonally, the description of organisms' accumulation was changed depending on the accumulation source whether from sediment or seawater.

The BAF values ranged (Fig. 2) between 0.005 and 85.0 for the organisms in the three different seasons (PoMon, PrMon, and Mon), hence they may be described as excluders (< 1.0), accumulator (1.0- 10.0) or hyper- accumulator (> 10.0) **(Zhao *et al.*, 2012)** of U-238 from whether sediment or seawater. This bio intake of U-238 may be influenced by external factors, whereas accumulation is more influenced by biology, organism behavior, and the feeding habits of a particular species, which might differ from ecosystem to ecosystem. The values of the BAF also depend on which parts or tissues of the organism are examined, besides age and size of the organisms are also important since small ones usually prefer other food than larger ones **(Meili, 1991; Karlsson *et al.*, 2002; Green, 2004)**. In light of the fact that in fish, different radionuclides accumulate in different tissues, e.g. strontium, radium, uranium, and plutonium accumulate in bones,. whereas cesium is fairly evenly distributed in the soft tissues **(Coughtrey *et al.*, 1985; Rowan & Rasmussen, 1994)**.

The demersal fish (*Leiognathus* sp.) describe as excluder (< 1.0) from sediment accumulation at all seasons with significant and lowest values (0.005) at Mon although the U SE recorded the highest value with 2181.89ppb at the same season. On the other hand, *Leiognathus* sp. is considered a hyper- accumulator (> 10.0) and accumulator from seawater during PoMon and PrMon, with U SW concentrations ofare 0.3 and 0.5ppb, respectively.

Beside those mentioned above, the explanation of these results may be related to the ability of marine fish to drink a large amount of water. Consequently, the radionuclides dissolved in the water column are prone to absorption in the gastro-intestine in marine species **(Poston & Klopfer, 1986)**. Additionally, the fish which are at a low position in the food chain (plankton feeders) e.g *Leiognathus* sp. (its food composition involved zooplankton of 40.76% and sand grains of 3.43%) tend to track variations in the water concentrations more closely than piscivorous fish **(Rowan & Rasmussen, 1994; Acharya & Naik, 2016)**. In addition, the results are compatible with **Kazoka *et al.* (2023)**, who concluded that the movement of radionuclides from water to fish was higher compared to the movement of radionuclides from sediment to fish also in the freshwater.

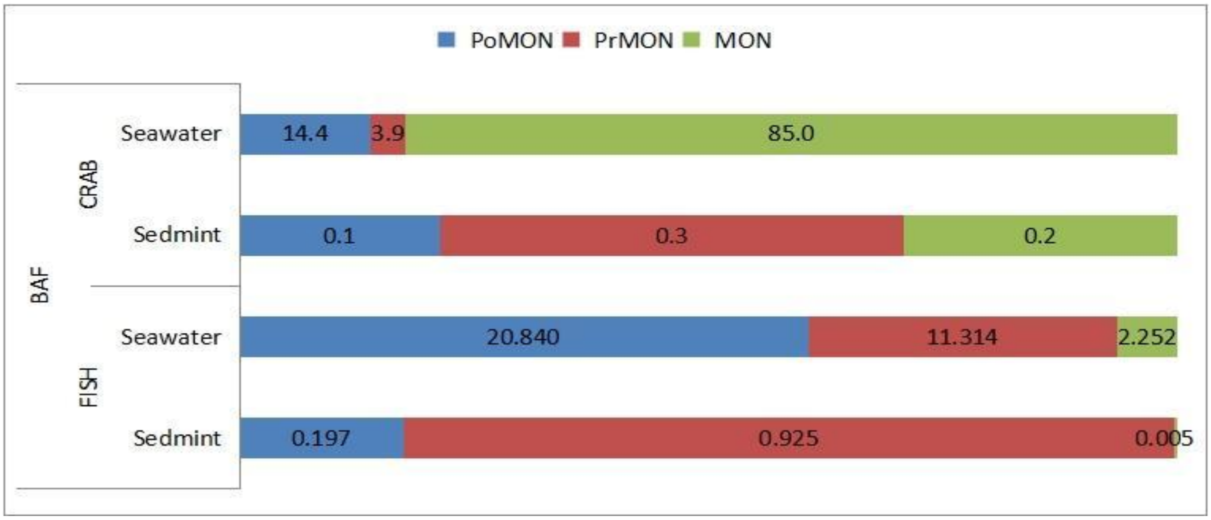

Fig. 3. Blot bar showing the BAF values of U-238 from the surrounding environment (sediment and seawater) by *Leiognathus* sp. and *P. sanguinolentus* during different seasons at MAPS

Unlike the BAF behavior of *Leiognathus* sp. in this study, on one hand, the three-spot swimming crab *P. sanguinolentus* is considered a hyper- accumulator (> 10.0) of U-238 from seawater with the highest values (85.0) during the Mon season against the low concentrations of U Sw (3.0, 5.0 and 4.8ppb), on the other hand *P. sanguinolentus* is described as an excluder (< 1.0) from the sediment throughout all seasons. The bioaccumulation behavior of *P. sanguinolentus* was seasonally fluctuated too, and that may be related to many reasons such as its habitat since this species is often associated with coastal intertidal and subtidal zones, consequently, this area is affected by Monson and most of time covered by the water as results of rainfall and strong wind **(Al-Sharif *et al.*, 2023)**. Additionally, those factors may contribute in the variations of the concentrations and solubility of U-238 in water **(Carvalho *et al.*, 2011; Khandaker *et al.*, 2015)**. Furthermore, there are also other seasonal factors which generally have an effect on thisese species, such as variation of temperature, salinity, food availability, photoperiod, and health condition **(Pillai & Thirumilu, 2012; Yang *et al.*, 2014; Waiho *et al.*, 2022; Kazoka *et al.*, 2023)**.

3. Estimated daily intake (EDI) and daily intake of radioactivity of U-238 (Di)

Given the hypothetical scenarios, 1st and 2nd EDI values of U-238 in fish were estimated. The values in both scenarios show (Table 1) the same seasonal fluctuation pattern and both are below the limit (Human daily intake has been estimated to range from 0.9 to 1.5ppb/ day) **(ATSDR, 1999)**.

For the 1st scenario (which assumed that the Indian individual will consume 0.08, while the Tamilar feeds on 0.37 annual per capita/ kg at 20-2021) the EDI values ranged between 0.0009 and 3.6E-5ppb/ day. The fluctuated pattern of the EDI values was compatible with the UF seasonal concentrations which recorded the highest values at

PoMon, while the lowest values were recorded at the Mon. On the other hand, the EDI values in the 2nd scenario gave the same seasonal pattern depending on the UF concentrations, however it recorded the highest values (ranging between 0.023 and 0.00397ppb/ day) compared to the 1st scenario.

Table 1. The EDI values of U-238 in fish and crab (ppb/ day) by the individual according to the hypothetical scenarios during different seasons at MAPS

Season	Fish				Crab			
	1st Scenario		2nd Scenario		1st Scenario		2nd Scenario	
	Annual per capita/kg							
	India	Tamil	India	Tamil	India	Tamil	India	Tamil
	0.08	0.37	6.31	9.3	0.09	0.32	6.31	9.3
	EDI							
PoMON	0.000211	0.000924	0.015645	0.023058	0.000156	0.000545	0.010836	0.015971
PrMON	0.000191	0.000837	0.014173	0.020889	6.95E-05	0.000243	0.004824	0.007109
MON	3.63E-05	0.000159	0.002696	0.003973	0.001466	0.005118	0.10177	0.149994

The EDI values of U-238 in crab exhibited the same seasonal pattern as UC in both scenarios but differed in range (1st scenario ranged between 0.0051 and 6.94E-05 while 2nd ranged from 0.14999 to 0.00482 at Mon and PrMon, respectively). This difference can be attributed to the consumption rate in both scenarios **(Khandaker *et al*., 2015)**. The compatibility of the seasonal pattern between the EDI values and UC may be related to the same factors of the bioaccumulation behavior of that species **(Coughtrey *et al.*, 1985; Meili, 1991; Rowan & Rasmussen, 1994; Karlsson *et al.*, 2002; Green, 2004)**.

Complementary to account for the daily concentration/ radioactivity intake of U-238 in fish/ crab by humans to enhance the data in this field, the DI (Table 2) values of radioactivity from consumption of one type of food (fish) for Tamilars recorded higher values (ranged from 0.000535 to 9.22695E-5 at PoMon and Mon, respectively) than the Indian individual (ranged from 0.000122 to 2.10308E-05 at PoMon and Mon, respectively). Additionally, the values of Di for the Indian/ Tamil individual who ate a specific amount of crab as dominant food recorded higher values (ranged from 0.002967551 to 0.00031597 at Mon and PrMon, respectively) than the Indian individual (ranged from 0.00084974 to 4.02757E-05 at Mon and PrMon, respectively). Logically, all the values take the same seasonal pattern like BAF and EDI, which are already related to the concentrations/ radioactivity of U-238 in the soft tissue of fish/carbs as written above. Furthermore, all those values are below the ICRP limit that is indicated by **Pandion and Arunachalam (2022)**, who noticed that the activities of U-238 in *Leiognathus equulus* and *P. sanguinolentus* samples were below the detection limit (BDL).

Table 2. The DI values of U-238 in fish and crab (Bq/ day) by the individual during different seasons at MAPS

Season	Fish		Crab	
	India	Tamil	India	Tamil
	Production kg/y			
	57000000.0	27000000.0	61000000.0	23000000.0
	Di			
PoMON	0.000122061	0.000535523	9.0476E-05	0.00031597
PrMON	0.000110579	0.00048515	4.02757E-05	0.000140655
MON	2.10308E-05	9.22695E-05	0.00084974	0.002967551

4. Committed dose from annual intakes (CD)

The committed effective dose in this investigation was estimated seasonally for fish and crap according to the both 1^{st} and 2^{nd} scenarios. For reasons of the radioactivity of U-238 in *Leiognathus* sp. and *P. sanguinolentus,* the CD (Table 3) takes the same seasonal pattern as mentioned above. The committed effective doses to adults due to ingestion of *Leiognathus* sp. as regular food at 1st and 2nd scenarios ranged from 1.36329E-06 to 3.1608E-09µSv/ yr at the PoMon and Mon, while due to the ingestion of *P. sanguinolentus* it ranged from 1.30707E-05 to 4.74884E-08µSv/ yr (Table 3) at the Mon and PrMon, respectively.

A comparison of the present results with the work carried out by other researchers, such as **Eckerman *et al.* (1999)**, **Iyengar *et al.* (2004)**, **Reeba *et al.* (2017)** and **Pandion and Arunachalam (2022)**, who reported that the annual committed dose due to ingestion to the population in Bangladesh, China, India, Japan, Pakistan, Philippines, Republic of Korea, and Vietnam ranged from 0.20 to 0.34mSv/ y shows that the CD values observed during the present work are below them and the proposed limit of 1mSv/ y by the ICRP. In view of **Giri *et al.* (2013)** results state that a large portion, at least one-eighth, of the mean annual dose due to natural sources is caused by the intake of food. The finding of this investigation suggests that *Leiognathus* sp. and *P. Sanguinolentus* from the study area at any season are safe for human consumption with respect to radiation exposure.

5. Lifetime cancer risk (LCR)

The United States Environmental Protection Agency's method **(USEPA, 1999)** was used to determine the lifelong cancer risk associated with consuming marine fish since longevity increases radiation exposure, which in turn increases the incidence of cancer. Long-lived radionuclides have no biological or radiological half-life, leading to a difficulty in estimating the cancer risk from their consumption **(Pandion & Arunachalam, 2022)**.

Table 3. The CD values of U-238 in fish and crab (Bq/ day) by the individual during different seasons at MAPS.

Season	Fish				Crab			
	1st Scenario		2nd Scenario		1st Scenario		2nd Scenario	
	Annual per capita/kg							
	India	Tamil	India	Tamil	India	Tamil	India	Tamil
	0.08	0.37	6.31	9.3	0.09	0.32	6.31	9.3
	CD							
PoMON	1.8345E-08	8.0486E-08	1.36329E-06	2.00929E-06	1.36E-08	4.74884E-08	9.4426E-07	1.3917E-06
PrMON	1.66194E-08	7.29152E-08	1.23505E-06	1.82029E-06	6.05319E-09	2.11396E-08	4.2034E-07	6.19519E-07
MON	3.1608E-09	1.38676E-08	2.34892E-07	3.46196E-07	1.27711E-07	4.46006E-07	8.86838E-06	1.30707E-05

As a follow-up to the work of numerous researchers who have recorded the lifetime cancer risk associated with the radioactive consumption of a range of seafood, Table (4) illustrates the LCR seasonal values of first and second scenarios from the ingestion of *Leiognathus* sp. and *P. sanguinolentus* which may accumulate U-238 in their flesh. The values are low as compared to the tolerable cancer risk of 10^{-3} for radiological risk and other investigations **(Petra *et al.*, 2013; Asaduzzaman *et al.*, 2015; Khandaker *et al.*, 2015; Pandion & Arunachalam, 2022; Priyadharshini *et al.*, 2023)**;, hence, there is no considerable radiation risk to people from the study area.

Table 4. The CD values of U-238 in Fish and crab (Bq /day) by the individual during different seasons at MAPS

Season	Fish				Crab			
	1st Scenario		2nd Scenario		1st Scenario		2nd Scenario	
	Annual per capita/kg							
	India	Tamil	India	Tamil	India	Tamil	India	Tamil
	0.08	0.37	6.31	9.3	0.09	0.32	6.31	9.3
	LCR							
PoMON	3.52407E-09	1.54614E-08	3.8513E-07	5.67624E-07	2.61218E-09	9.12252E-09	2.66753E-07	3.93155E-07
PrMON	3.19258E-09	1.4007E-08	3.48903E-07	5.14231E-07	1.16282E-09	4.06092E-09	1.18746E-07	1.75014E-07
MON	6.0719E-10	2.66396E-09	6.6357E-08	9.78004E-08	2.45333E-08	8.56777E-08	2.50532E-06	3.69247E-06

6. Risk quotient (RQ)

The risk quotient (RQ) method allows for a fast assessment of environmental risk; it is the ratio of existing measurement to the permissible standard value, where the strictest standard is often adopted. According to the seasonal concentration of U-238 (ppb) in both *Leiognathus* sp. and *P. sanguinolentus* RQ values were calculated (Fig. 4). In this investigation, all RQ values were ≤ 1 and ranged from 0.000002153 to 1.24958E-05 and from 3.8528E-06 to 8.12868E-05 for *Leiognathus* sp. and *P. sanguinolentus*, respectively.

For the 1st scenario (which assumed that the Indian individual will consume 0.08, while the Tamilar feeds on 0.37 annual per capita/ kg at 20-2021), the EDI values ranged between 0.0009 and 3.6E-5ppb/ day. The fluctuated pattern of the EDI values is compatible with the UF seasonal concentrations which recorded the highest values during PoMon, while the lowest were recorded during the Mon. On the other hand, the EDI values in the 2nd scenario gave the same seasonal pattern depending on the UF concentrations, however it recorded the highest values (ranging between 0.023 and 0.00397ppb/ day) compared with the 1st scenario.

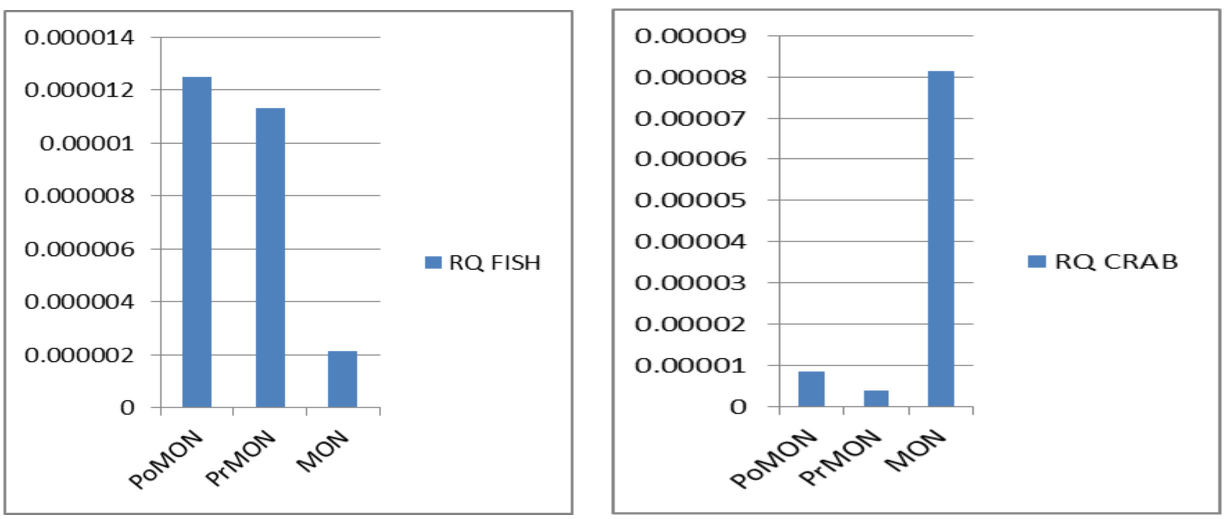

Fig. 4. Blot bar showing the RQ values of U-238 during different seasons at MAPS

CONCLUSION

From the findings of this research, it can be concluded that the values of enrichment factor (EF), bioaccumulation factor (BAF), estimated daily intake (EDI), daily intake of radioactivities (DI), committed dose from annual intakes (CD), lifetime cancer risk hazard (LCR), and risk quotient (RQ) indexes are below the limit in view of the hypothetical 1st and 2nd scenarios. Our finding is considerable that there is no radiation/ chemical risk from the consumption of *Leiognathus* sp. and *P. sanguinolentus*, which constitute the dominant diet surrounding the Madras Atomic Power Station (MAPS), Chennai India.

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REFERENCES

Abbasisiar, F.; Hosseini, T.; Fathivand, A. and Heravi, G. (2004). Determination of uranium isotopes (234U, 238U) and natural uranium (U-nat) in water samples by alpha spectrometry:pp.35-40.

Acharya, K. V. and Naik, S. D. (2016). Food and feeding habit of pony fish, Leiognathus splendens (Cuvier, 1829) off Ratnagiri coast, Maharashtra. International Journal of Scientific and Engineering Research, 7(9): 95-100.

AL-Sharif, S. A. ; Chapara, M. ; El-Taher, A.; ElBessa, M. and Osman, A. G., (2023). Study of the Synergistic Effects of Meteorological, Oceanographic, Biological, and Radiological Parameters (MOBR) on Marine Ecosystems Around a Nuclear Power Plant. Egyptian Journal of Aquatic Biology and Fisheries, 27(5): 1393-1413.

Asaduzzaman, K.; Khandaker, M. U.; Amin, Y. M. and Mahat, R. (2015). Uptake and distribution of natural radioactivity in rice from soil in north and west part of peninsular Malaysia for the estimation of ingestion dose to man. Annals of Nuclear Energy, 76: 85-93.

ATSDR (1999). Toxicological profile for uranium. Agency for Toxic Substances and Disease Registry. US Public Health Service. Department of Health & Human Services, Atlanta GA.

Bamuwamye, M.; Ogwok, P. and Tumuhairwe, V. (2015). Cancer and non-cancer risks associated with heavy metal exposures from street foods: evaluation of roasted meats in an urban setting. Journal of Environment Pollution and Human Health, 3(2): 24-30.

Barbieri, M. J. J. G. G. (2016). The importance of enrichment factor (EF) and geoaccumulation index (Igeo) to evaluate the soil contamination. J Geol Geophys, 5(1): 1-4.

Biswas, K.P.; Hossain, S.; Deb, N.; Bhuian, A.K.M.S.I.; Gonçalves, S.C.; Hossain, S. and Hossen, M.B. (2021). Assessment of the Levels of Pollution and Their

Risks by Radioactivity and Trace Metals on Marine Edible Fish and Crustaceans at the Bay of Bengal (Chattogram, Bangladesh). Environments., 8(2):13.

Brunskill, G. J. and Wilkinson, P. (1987). Annual supply of uranium-238, uranium-234, thorium-230, radium-226, lead-210, polonium-210, and thorium-232 to Lake 239 (Experimental Lakes Area, Ontario, Canada) from terrestrial and atmospheric sources. Can J Fish Aquat Sci, 44(1): 215-230.

Carvalho, F. P.; Oliveira, J. M. and Malta, M. (2011). Radionuclides in deep-sea fish and other organisms from the North Atlantic Ocean. ICES Journal of Marine Science, 68(2): 333-340.

Chiara, C.; Conti, G. O.; Carlo, S.; Marmiroli, S.; Salvatore, S.; Vinceti, M. and Margherita, F. (2013). Risk assessment for metals and PAHs by mediterranean seafood. Food and Nutrition Sciences, 14: 10-13.

Coughtrey, P. J.; Jackson, D.; Martin, A. and Thorne, M. C. (1985). Actinide discharges from Sellafield-a summary of behaviour in the environment and the radiological implications (No. ANS--429). Associated Nuclear Services.

Eckerman, K. F.; Leggett, R. W.; Nelson, C. B.; Puskin, J. S. and Richardson, A. C. (1999). Cancer risk coefficients for environmental exposure to radionuclides. Federal Guidance Report: 13.

Fasae, K. P. and Isinkaye, M. O. (2018). Radiological risks assessment of 238U, 232Th, and 40K in fish feeds and catfish samples from selected fish farms in Ado–Ekiti, Nigeria. Journal of radiation research and applied sciences, 11(4): 317-322.

Fisheries Statistic Division (2022). Hand book on fisheries statistics, annual report, department of fisheries, ministry of fisheries animal husbandry and dairying, Government of India. https://dof.gov.in/sites/default/files/202301/HandbookFisheriesStatistics19012023.pdf

Ghose, S.; Alam, M. N. and Islam, M. N. (2000). Radiation dose estimation from the analysis of radionuclides in marine fish of the Bay of Bengal. Radiation protection dosimetry, 87(4): 287-291.

Giri, S.; Jha, V. N. ;Singh, G. and Tripathi, R. M. (2012). Dose estimates for the local inhabitants from 210Po ingestion via dietary sources at a proposed uranium mining site in India. International journal of radiation biology, 88(7): 540-546.

Green, T. F. (2004). Marine Science: Marine Biology and Oceanography. Perfection Learning. New York.

Hutchinson, F.(1966). The molecular basis for radiation effects on cells. Cancer research 26.9_Part_1: 2045-2052.

Iyengar, G. V.; Kawamura, H.; Dang, H. S.; Parr, R. M.;Wang, J. W.; Akhter, P., ... and Nguyen, M. S. (2004). Estimation of internal radiation dose to the adult Asian population from the dietary intakes of two long-lived radionuclides. Journal of environmental radioactivity, 77(3): 221-232.

Karlsson, S.; Meili, M. and Bergström, U. (2002). Bioaccumulation factors in aquatic ecosystems. A critical review. Swedish Nuclear Fuel and Waste Management CoStockholm Sweden.

Kathren, R. L. and Burklin, R. K. (2008). Acute chemical toxicity of uranium. Health Physics, 94(2), 170-179.

Kazoka, A. R.; Mwalilino, J. and Mtoni, P. (2023). A radiological risk Assessment of 226Ra, 228Ra and 40K isotopes in tilapia fish and its granitic environment in Singida municipality, Tanzania. Earth, 4(3): 540-551.

Khan, H. M.; Ismail, M.; Khan, K. and Akhter, P. (2011). Measurement of radionuclides and gamma-ray dose rate in soil and transfer of radionuclides from soil to vegetation, vegetable of some Northern areas of Pakistan using γ-ray spectrometry. Water, Air, & Soil Pollution, 219; 129-142.

Khandaker, M. U.; Asaduzzaman, K.; Nawi, S. M.; Usman, A. R.; Amin, Y. M.; Daar, E., ... and Okhunov, A. A. (2015). Assessment of radiation and heavy metals risk due to the dietary intake of marine fishes (Rastrelliger kanagurta) from the Straits of Malacca. PLoS One, 10(6): e0128790.

Klerks, P.L. and Levinton, J.S. (1989). Rapid evolution of metal resistance in a benthic oligochaete inhabiting a metal-polluted site. Biol Bull 176:135-141.

Leggett, R. W. and Harrison, J. D. (1995). Fractional absorption of ingested uranium in humans. Health physics, 68(4): 484-498.

Meili, M. (1991). The coupling of mercury and organic matter in the biogeochemical cycle—towards a mechanistic model for the boreal forest zone. Water Air & Soil Pollution, 56: 333-347.

Pandion, K. and Arunachalam, K.D. (2022). Potential health risk estimation of naturally occurring radionuclides intake due to the consumption of seafood around Coastal zone. J Food Sci Nutr The 8(1): 028-037.

Patra, A. C.; Mohapatra, S.; Sahoo, S. K.; Lenka, P.; Dubey, J. S.; Tripathi, R. M. and Puranik, V. D. (2013). Age-dependent dose and health risk due to intake of uranium in drinking water from Jaduguda, India. Radiation protection dosimetry, 155(2): 210-216.

Pillai, S. L., and Thirumilu, P. (2012). Fishery, biology, and yield estimates of Portunus sanguinolentus off Chennai. Journal of the Marine Biological Association of India, 54(1):73-76.

Poston, T. M. and Klopfer, D. C. (1986). Literature review of the concentration ratios of selected radionuclides in freshwater and marine fish.

Priyadharshini, M.; Ahmed, M. S.; Pradhoshini, K. P.; Santhanabharathi, B.; Ahmed, M. F. S.; Alam, L., ...and Musthafa, M. S. (2023). Human health risk assessment due to consumption of dried fish in Chennai, Tamil Nadu, India: a baseline report. Environmental Science and Pollution Research: 1-14.

Reeba, M. J.; Anilkumar, S. and Jojo, P. (2017). Ingestion dose due to primordial radionuclides in the food crops grown in HBRA in Kerala. Int J Theor Appl Mech, 12: 785-795.

Shyam, S. Salim; Sathiadhas, R.; Narayana, R.; Katiha; Pradeep, K.; Krishnan, M. Biradar, R.S., Gopal, Nikita; Barik, N. and Ganesh, B. (2013). Rural livelihood security: Assessment of fishers‘ social status in India. Agricultural Economics Research Review. 26:21-30.

Sinex, S. A. and Helz, G. R. (1981). Regional geochemistry of trace elements in Chesapeake Bay sediments. Environmental Geology, 3(6): 315-323.

Swanson, S. M. (1985). Food-chain transfer of U-series radionuclides in a northern Saskatchewan aquatic system. Health physics, 49(5):747-770.

Uidai (2020) Unique Identification Authority of India. anuual report New Delhi – 110001 https://uidai.gov.in/images/state-wise-aadhaar-saturation.pdf

UNSCEAR (2000). (United Nations Scientific Committee on the Effects of Atomic Radiation) Sources and effects of ionizing radiation, Report to the general assembly with annexes, United Nations Hereditary effects of radiation. United Nations.

USEPA (1999). (United States Environmental Protection Agency) Cancer Risk Coefficients for Environmental Exposure to Radionuclides, Federal Guidance Report N 13. EPA 402-R-99-001, Office of Radiation and Indoor Air.

USEPA (2006). (United States Environmental Protection Agency) Effect determination for Atrazine. Appendix F: The risk quotient method and levels of concern. Office of Pesticide Programs, Washington, DC.

USEPA(1996). (United States Environmental Protection Agency) Proposed Guidelines for Carcinogen Risk Assessment. Washington, DC: Office of Research and Development.

Waiho, K.; Rozaimi, R.; Poompuang, S.; Tunkijjanukij, S.; Shu-Chien, A. C.; Wang, Y., ... and Fazhan, H. (2022). Population Biology, Reproductive Biology, Fisheries, and Future Perspective to Develop Three-Spot Swimming Crab Portunus sanguinolentus as New Aquaculture Candidate: A Review. Journal of Fisheries and Environment, 46(2): 116-135.

Yang, C. P.; Li, H. X.; Li, L., and Yan, Y. (2014). Occurrence and effects of the rhizocephalan parasite Diplothylacus sinensis (Cirripedia: Rhizocephala: Thomsoniidae) in the swimming crab Portunus sanguinolentus (Decapoda: Portunidae) in Honghai Bay, South China Sea. Journal of Crustacean Biology, 34(5): 573-580.