Malaysian Journal of Analytical Sciences (MJAS)
Published by Malaysian Analytical Sciences Society

RADIOLOGICAL RISKS RELATED TO NATURAL RADIONUCLIDE IN SELECTED FISH FROM EAST COAST OF PENINSULAR, MALAYSIA

(Risiko Radiologi Berkaitan Radionuklid Tabii Dalam Ikan Terpilih Dari Pantai Timur Semenanjung, Malaysia)

Muhammad Nur Rashidi Rosli[1*], Madihah Jafar Sidik[2], Wahmisari Priharti[3], and Nurashikin Abd Azis[4]

[1]Preparatory Centre for Science and Technology,
Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia
[2]Borneo Marine Research Institute,
Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia
[3]Telkom University, J1. Telekomunikasi No.1, Dayeuhkolot, Kab. Bandung, Indonesia
[4]Faculty of Security and Governance,
North Borneo University College, 88450 Kota Kinabalu, Sabah

**Corresponding author: mnrashidirosli@ums.edu.my*

Received: 12 July 2022; Accepted: 27 February 2023; Published: 19 April 2023

Abstract

Systematic investigations are essential in establishing the current water quality because numerous industrial and anthropogenic sources are responsible for polluting the ecosystem along Peninsular Malaysia's east coast. Since aquatic stocks play a significant role in the daily diets of the surrounding populations, the present study used the ICP-MS technique to measure the levels of three natural radionuclides ^{232}Th, ^{238}U and ^{40}K in three fish species collected from three locations along the east coast of Peninsular Malaysia. The activity concentration ranges from 23.13 ± 1.70 to 43.31 ± 2.10 Bq kg^{-1}for ^{40}K, 0.06 ± 0.01 to 0.33 ± 0.05 Bq kg^{-1} for ^{232}Th and 0.11 ± 0.08 to 0.48 ± 0.10 Bq kg^{-1} for ^{238}U. The determined activity concentration of radionuclides was used to estimate the annual effective dose and cancer risk. The findings showed that the predicted yearly effective doses (μSv year^{-1}) for ^{232}Th, ^{238}U and ^{40}K were 1.67, 0.70, and 11.92 correspondingly, which were much lower than the UNSCEAR recommendation and considered to be safe. Based on the estimated annual effective dose and a life expectancy of 70 years, the cancer risk factor for adults is predicted to be 3.00×10^{-5}. Compared to the UNSCEAR cancer risk factor of 8.4×10^{-3} and ICRP cancer risk factor of 3.5×10^{-3}, this value is much lower. According to the current study, the dose that locals consume from eating fish is safe for human consumption, relatively minimal, and does not impair human health.

Keywords: Bioaccumulation, natural radionuclide. activity concentration, ingestion dose, cancer risk

Abstrak

Penyiasatan sistematik adalah penting dalam menentukan kualiti air semasa kerana banyak sumber perindustrian dan antropogenik bertanggungjawab dalam mencemarkan ekosistem di sepanjang pantai timur Semenanjung Malaysia. Memandangkan stok akuatik memainkan peranan penting dalam diet harian populasi sekitar, kajian ini menggunakan teknik ICP-MS untuk mengukur tahap tiga radionuklid semula jadi ^{232}Th, ^{238}U dan ^{40}K dalam tiga spesies ikan yang dikumpulkan dari tiga lokasi di sepanjang pantai

timur Semenanjung Malaysia. Kepekatan aktiviti berkisar antara 23.13 ± 1.70 hingga 43.31 ± 2.10 Bq kg^{-1}untuk ^{40}K, 0.06 ± 0.01 hingga 0.33 ± 0.05 Bq kg^{-1} untuk ^{232}Th dan 0.11 ± 0.08 hingga 0.48 ± 0.10 Bq kg^{-1} bagi ^{238}U. Kepekatan aktiviti radionuklid yang ditentukan telah digunakan untuk menganggarkan dos berkesan tahunan dan risiko kanser. Penemuan menunjukkan bahawa dos berkesan tahunan yang diramalkan (μSv $tahun^{-1}$) untuk ^{232}Th, ^{238}U dan ^{40}K adalah masing-masing 1.67, 0.70, dan 11.92, yang jauh lebih rendah daripada pengesyoran UNSCEAR. Berdasarkan anggaran dos berkesan tahunan dan jangka hayat 70 tahun, faktor risiko kanser untuk orang dewasa diramalkan ialah 3.00×10^{-5}. Berbanding dengan faktor risiko kanser UNSCEAR sebanyak 8.4×10^{-3} dan faktor risiko kanser ICRP sebanyak 3.5×10^{-3}, nilai ini jauh lebih rendah dan selamat. Menurut kajian semasa, dos yang diambil oleh penduduk tempatan daripada memakan ikan adalah selamat untuk dimakan manusia, agak minimum, dan tidak menjejaskan kesihatan manusia.

Kata kunci: Bioakumulasi, radionuklid semula jadi. kepekatan aktiviti, dos pengambilan, risiko kanser

Introduction

Radionuclides in the water may contribute to internal exposure more frequently by ingestion, despite the fact that people are constantly exposed to external radiation from cosmic and terrestrial sources. ^{232}Th and ^{238}U are two prominent examples of radioactive elements that spontaneously decay and release energy, subatomic particles, and the remainder, or smaller offspring nuclei than the original [1]. The majority of the radioactive decay in the natural decay ^{232}Th and ^{238}U are gamma emitters, which are a significant source of external exposures [2]. However, some of their decay products, such as ^{222}Rn, are alpha emitters, while others, such as ^{214}Bi are beta emitters, with ^{40}K potentially producing more internal exposure routes from environmental sources. These levels can be increased by anthropogenic activities, which are subsequently enhanced by artificial radioactive sources released into the environment [2–4].

By nature of undersea earthquakes, underwater volcanic activity, weathering and mineral recycling of terrestrial rocks, and movement of the seabed, seawater naturally includes radioactivity [5]. The ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) decay series radionuclides are consequently transferred to water through leaching action as a result of extensive contact with a variety of minerals and geological materials, such as igneous rocks and ores, which frequently contain high concentrations of natural radionuclides [6]. It is known that human activities, such as the burning of fossil fuels in coal-fired power plants, the extraction of natural gas and oil, the mining and processing of ores, and the manufacturing of these fuels, enhance naturally occurring radioactivity in aquatic ecosystems. The reprocessing of spent nuclear fuel, underwater nuclear device testing, nuclear power plant leak accidents, and the post-nuclear disposal of hazardous and radioactive material are further anthropogenic contributors [1, 7-9].

Because uranium and thorium radionuclides enter the human body predominantly through food intake and only to a much lesser extent through respiration, the breakdown sequence of these radionuclides is crucial [10]. In the meantime, ^{40}K is significant since it is a marine environment radionuclide with a long half-life (1.25 × 109 years) [11]. Even though radionuclides in the ocean exhibit complex behaviours (for example, uranium is quite soluble in sea water while thorium is almost completely insoluble, radium and radon are soluble in water), they can spread throughout the marine ecosystem in a number of ways, including by becoming dissolved in the seawater, attached to plankton suspended in the seawater, attached to sediment on the seabed, and through contaminated marine organisms, such as fish, shellfish, and other seafood [12]. Therefore, a deeper understanding of the concentration of radionuclide activity in various reference organisms is crucial to estimating radiological risk to the environment [13].

Due to their high toxicity and the cumulative behaviour of these creatures, the dissolution of radionuclides into seawater adversely affects the biological balance of the environment and the activity of aquatic organisms [14]. For evaluating radiological effects on human health and marine environment, radionuclide concentrations in seawater and marine life are crucial inputs [15]. It is common knowledge that marine creatures naturally accumulate radionuclides, and that they can offer valuable data for radio-ecological and radiological

research [16, 17]. Fish and seafood are significant sources of protein for many developing nations and are significant dietary sources in many regions of the world [18]. In terms of total consumption and protein content per capita, Malaysia is regarded as one of Southeast Asia's top seafood eaters [19].

The distribution of radioactivity in seafood varies depending on feeding habits and origin areas [3, 5, 22]. Since the consumption of marine fish is among the highest in the world, it is relevant to note that the information on the radionuclide balance in sea fish is of correspondingly larger value [20, 22]. Human uptake is obviously influenced by food habits. The literature that is currently accessible still lacks information on the bioaccumulation and distribution of natural radionuclides in sea fish and sea water. Given the importance of this information, the current study's objectives are to assess the activity concentrations of ^{232}Th, ^{238}U and ^{40}K in edible marine life caught along Peninsular Malaysia's east coast, as well as the ingestion dose, and the risk of cancer for the local population. This information could be used to inform public health policies and recommendations related to seafood consumption and environmental protection in the region.

Materials and Methods

Samples and sampling location

The east coasts of Peninsular Malaysia were chosen to gather fresh samples of three different species of fish: *Rastrelliger, Megalaspis cordyla*, and *Decapterus maraudsi*. Nine samples total, ranging in mass from 125 to 260 g, were collected for each location, three samples from each species. These study locations were selected because of their biodiversity and fish farming methods, which serve as important sources of seafood for Peninsular Malaysia. The samples were taken between March 2016 and February 2017, from coastal locations of Tanjung Lumpur (3.759865° N, 103.315066° E) in Pahang, Kerteh (4.5079° N, 103.4430° E) in Terengganu, and Chendering (5.2666° N, 103.1656° E) in Terengganu, all of which are bordered by several fishing communities. In each situation, there are multiple gas-fired power plants close by, including the 324 MW Petronas power plant in Pahang, the 1136 MW Sultan Ismail power plant in Terengganu, and the 808 MW Paka power station in Terengganu. These are also well known for a few offshore sectors such as petrochemical and metal refining sectors.

Sample treatment

To separate the head, stomach contents, gills, and tissues of the fish flesh, the fish samples were first rinsed in distilled water. Fish samples of known weight were cleaned with distilled water and dried in an oven at 80 °C to stabilise the weight. This dry sample was ground into fine granules of about 500 m. The following step involved combining 0.1 g of sample with 4.0 mL of nitric acid and 6.0 mL of hydrochloric acid. A clear solution was created by digesting the mixture in a microwave for 55 minutes. Following filtering, distilled water was added until the volume of the sample solution reached 100 mL, at which point its radionuclide concentration was evaluated using ICP-MS technique. To prevent potential contamination from digestion processes, 5 standards and 1 blank solution were run using the same reagents in each case. Control sample were used in this study and treated in the same way as the fish samples from the East Coast of Peninsular Malaysia, except that they not come from the study area and therefore serve as a comparison group.

Sample analysis

An Induced Coupling Mass-Plasma Spectrometer (ICP-MS) that was calibrated using the SRM standard MA-A-2 (TM) Fish Flesh Homogenate was used to analyse samples that had been produced in solution form [21, 22]. ICP-MS is the combination of a mass spectrometer and an ICP (Induced Coupled Plasma) high temperature source. The atoms of the elements in the sample are changed into ions by the ICP source. A mass spectrometer is then used to separate and find these ions [23]. As shown in Table 2, ICP-MS generated radionuclide weights (w), which were used to calculate the concentration of radionuclide activity (A).

Determination of radionuclide activity concentration, annual effective dose and cancer risk

The concentration of radionuclide activity, A (Bq kg^{-1}) was determined using Equation (1) below

$$A = \frac{\lambda \theta N_A}{M} \times \frac{w}{W} \quad (1)$$

Where λ is the decay constant of the radionuclide, θ is the abundance of radionuclides in the universe, N_A (mol^{-1}) is the Avogadro constant, M (g mol^{-1}) is the molecular weight of the radionuclide. W (g) is the sample weight and w (mg kg^{-1}) are the natural radionuclide content in the sample obtained from ICP-MS [21, 22]. The values of w dan A for the three radionuclides are shown in Table 2.

From ^{232}Th, ^{238}U dan ^{40}K activities, the annual effective dose, D (µSv year^{-1}) is calculated using Equation 2 below

$$D = I \times A \times E \quad (2)$$

Where I (kg tahun^{-1}) is the annual fish intake rate of 57.3 kg year^{-1} [24], A (Bq kg^{-1}) is the concentration of radionuclide activity and E (µSv Bq^{-1}) is the factor conversion of radionuclide activity to dose for adults (> 17 years) [25]. Assuming that an individual's life expectancy is 70 years, R is estimated from Equation 3 below

$$R = D \times 70 \times (5 \times 10^{-8}) \quad (3)$$

Where, 5×10^{-8} (µSv^{-1}) is a cancer risk factor for low doses [26]. This research focused on the population for the age category> 17 (adults) because adults are the main consumers of Malaysian fish [22, 24]. The annual effective dose of D (µSv year^{-1}) and cancer risk R, are as in Table 3.

Results and Discussion

Activity concentrations of ^{232}Th, ^{238}U and ^{40}K

ICP-MS showed average natural radionuclide content of ^{232}Th (^{228}Ra), ^{238}U (^{226}Ra) and ^{40}K in the samples. From these, calculations were performed using Equation (1) to estimate the concentration of radionuclide activity. ^{232}Th (^{228}Ra) concentrations in marine environment is substantially lower than that of ^{238}U (^{226}Ra) when it comes to natural radionuclides. The findings are consistent with uranium's solubility in water and thorium's low solubility [4, 27], which are somewhat counterbalanced by thorium's higher abundance in the earth's crust. The dry weight basis activity concentrations of the examined radionuclides in fish, along with their uncertainties, are reported in Table 1. In turn, it may be anticipated that the accumulation of thorium in marine fish will be somewhat lower than that of the uranium chain nuclides.

For all three study sites, the current analysis reveals higher quantities of ^{238}U than ^{232}Th in the fish. Between the three research locations, there is also a significant difference ($p < 0.05$) in the concentrations of ^{238}U and ^{232}Th in the fish samples, according to statistical analysis (ANOVA). In addition, the spread of ^{232}Th, ^{238}U and ^{40}K in aquatic ecosystems can occur through solid suspension which in turn involves other aquatic components such as plankton and coral reefs. The chemical nature of the water, the physiology of the fish including the feeding behaviour and digestion of food by the fish can also affect the number of radionuclides accumulated in the body of the fish [2 - 4, 23]. *Megalaspis cordyla* had the lowest mean activity of ^{238}U among fin fishes, at 0.11 ± 0.08 Bq kg^{-1}, and the highest was 0.48 ± 0.10 Bq kg^{-1} (*Rastrelliger*). The small differences in ^{238}U uptake by the studied fishes may be explained by biological factors unique to each fish, including feeding habits, particulate ingestion with food (in the case of *Rastrelliger*, which has a varied diet regardless of the prey species, such as macroplankton and fish larvae), physiological behaviour, and the radionuclide distribution within the marine compartments [28].

When levels in other places are compared, Table 2 demonstrates that the current values of ^{238}U accord with those that have been previously reported from the same sites [5] and from the Indian coastal seas [29], but less so than the data from the Aleutian Islands [28] and Nigeria [30]. The outcomes in each of these situations are far worse than what is now observed. In contrast, Rosli et al. 2018 [22] reported average activity ranges for ^{232}Th and ^{238}U in the soft tissue of fish collected from the Terengganu coast in Malaysia of 0.30 to 0.51 Bq kg^{-1} and 1.07 to 1.15 Bq kg^{-1}, respectively. Compared to ^{238}U in fish, the mean activity of ^{232}Th in fishes ranging from 0.06 ± 0.01 Bq kg^{-1} (*Megalaspis cordyla*) to 0.33 ± 0.05 Bq kg^{-1} (*Decapterus maraudsi*). This finding

confirms that thorium is insoluble in water and that uranium is soluble in it [4]. The outcomes are comparable to those of a prior study done on various fish species in the same study settings [3]. However, no significant differences were found for the ^{232}Th activity in the literature (Table 2), with the exception of the Ondo area of Nigeria [30], regardless of fish species or study sites.

According to Table 1, the average activity concentration of ^{40}K was often higher than that of ^{232}Th and ^{238}U activities. This is to be expected as this radionuclide is widely distributed in marine environments and is involved in the metabolism of species living there [31]. The fin fishes measured at this time have similar mean ^{40}K activity, ranging from 23.13 ± 1.70 Bq kg^{-1} 1 (*Megalaspis cordyla*) to 43.31 ± 2.10 Bq kg^{-1} (*Megalaspis cordyla*). The significantly higher findings for ^{40}K are consistent with expectations given that the potassium-rich fish bones make up a significant portion of the weight of each sample. Due to its great natural abundance, the discovery of 40K in every sample was anticipated [32]. The current ^{40}K results are consistent with previous fish investigations conducted at the same site (Tanjung Lumpur, Pahang), with values ranging from of 31.55 ± 2.20 Bq kg^{-1} to 32.10 ± 1.90 Bq kg^{-1} [5]. A quick review of the literature reveals a heterogeneous distribution of ^{40}K in various areas. For example, fish collected from the water near Vizag, India [33] had a relatively lower mean activity of ^{40}K, while fish from the coastal waters near oil producing regions in Nigeria [30], India [29], and the North Atlantic Ocean [11] had significantly higher concentrations.

Furthermore, it was discovered that the areas surrounding Tanjung Lumpur, Pahang, had the highest quantities of all detected radionuclides in fish samples. The diverse range of activity (such as housing, tourism, power plants, petroleum, chemical industries, etc.) in the Tanjung Lumpur area, as well as industrial and urbanisation effluents, may be contributing to an increase in radionuclide concentrations in the marine environment. These are just a few of the many potential causes. The range of results reported by earlier studies overlaps with the concentration of radioactive activity recorded in this investigation. This shows that the findings of this study are consistent with those of earlier research, as seen in Table 2.

Table 1. Arithmetic mean + SD of ^{226}Ra, ^{228}Ra and ^{40}K activity concentration (Bq kg^{-1}) and annual effective dose (μSv y^{-1}) due to the ingestion of collected fishes (d.w.)

Sample Code	Radionuclides	Mean Activity Concentration, *A* (Bq kg^{-1})			Grand Mean Activity Concentrations *A* (Bq kg^{-1})	Annual Effective Dose, *D* (μSv y^{-1})
		Tanjung Lumpur (Pahang)	Kerteh (Terengganu)	Chendering (Terengganu)		
FS	^{232}Th	0.33 ± 0.05	0.12 ± 0.02	0.08 ± 0.01	0.18 ± 0.03	2.37
	^{238}U	0.36 ± 0.08	0.19 ± 0.05	0.12 ± 0.07	0.22 ± 0.06	0.57
	^{40}K	31.55 ± 2.20	39.01 ± 2.80	24.03 ± 1.80	31.53 ± 8.65	11.12
FC	^{232}Th	0.09 ± 0.03	0.07 ± 0.01	0.06 ± 0.01	0.07 ± 0.02	0.92
	^{238}U	0.26 ± 0.10	0.11 ± 0.08	0.11 ± 0.02	0.16 ± 0.06	0.41
	^{40}K	43.31 ± 2.10	41.27 ± 3.20	23.13 ± 1.70	35.91 ± 12.83	12.76
FK	^{232}Th	0.19 ± 0.07	0.12 ± 0.05	0.09 ± 0.01	0.13 ± 0.04	1.71
	^{238}U	0.48 ± 0.10	0.43 ± 0.08	0.39 ± 0.12	0.43 ± 0.10	1.11
	^{40}K	32.10 ± 1.90	37.66 ± 2.20	30.63 ± 2.00	33.47 ± 4.28	11.89

Table 2. Comparisons of radionuclide activity concentration, A (Bq Kg^{-1}) with previous study

Sample Name	Mean Activity Concentrations A (Bq kg^{-1})			Location	References
	^{232}Th	^{238}U	^{40}K		
Decapterus maraudsi	0.08 – 0.33	0.12 – 0.36	24.03 – 39.01	Malaysia	Present study
Megalaspis cordyla	0.06 – 0.09	0.11 – 0.26	23.13 – 43.31	Malaysia	Present study
Rastrelliger	0.09 – 0.19	0.39 – 0.48	30.63 – 37.66	Malaysia	Present study
Not specified	0.19 – 0.74	0.63 – 2.19	22.10 – 100.20	Malaysia	Khandaker et al. [5]
	-	0.118 – 0.468	56.0 – 70.7	USA	Hong et al. [28]
	ND – 1.50	ND – 1.00	48 -230	Malaysia	Amin et al. [3]
	0.47 – 1.35	0.50 – 1.67	31.2 – 42.6	Malaysia	Khandaker et al. [5]
	0.28 – 1.02	0.50 – 0.95	31.8 – 58.30	Malaysia	Khandaker et al. [5]
	35.9 – 62.9	24.5 – 70.0	586 - 836	Nigeria	Ademola and Eheidu [30]
	0.58	0.105	64.3 ± 0.5	India	Narayana [29]
	0.30 – 0.51	0.10 – 1.00	36.70 – 82.38	Malaysia	Rosli et al. [22]
	0.25 – 0.31	1.07 – 1.15	470 - 486	Irish and North Sea	IAEA 2013 [35]
	-	2.0 – 30.2	32 - 149	Portugal	Carvalho [11]

Annual effective dose

Humans are exposed to radiation from natural sources on average at a rate of 2.4 mSv per $year^{-1}$ [2]. The average annual absorption dose for the radioactive series of uranium and thorium was 0.12 mSv $year^{-1}$ and 0.17 mSv $year^{-1}$, respectively, totalling 0.29 mSv $year^{-1}$ [2, 32]. Human exposure levels, however, differ based on geology, geography, and climate [2]. The presence of heavy metals and natural radioactivity has an impact on this level as well [34]. The effective dosage to humans is further increased by the anthropogenic radioactive content of fish and the absorption of radionuclides through diet [11].

The daily intake of ^{40}K was discovered to be significantly higher ($p < 0.001$) than that of the other radionuclides by ANOVA analysis. Intakes of ^{238}U (1.7%) and ^{232}Th (1.1%) are insignificant when compared to the radionuclide ^{40}K. (96.7 %). According to Table 3, ^{40}K was responsible for the greatest annual effective dosage of 11.92 Sv $year^{-1}$. However, the ^{40}K content in the body is tightly homeostatically regulated, meaning that it is not impacted by changes in radionuclide levels in the environment. Instead, the actively maintained amount is managed by the body to reach the typical range needed for system operation [33, 36, 37]. Adult males have roughly 3700 Bq of ^{40}K, which means that the amount of ^{40}K in the body is constant. This isotope administers a dose to soft tissue of 0.18 mSv $year^{-1}$ and to bone of 0.14 mSv $year^{-1}$ [34, 38].

Between the study locations, there are significant differences ($p < 0.05$) in the annual effective dose of ^{238}U and ^{232}Th. While ^{232}Th provided 1.67 µSv $year^{-1}$ and ^{238}U contributed 0.70 µSv $year^{-1}$ of the annual effective dosage, respectively. When compared to earlier studies [11, 13], the annual effective dosage brought on by the

ingestion of ^{232}Th and ^{238}U radionuclides is incredibly low. The findings of this study also demonstrated that the yearly effective dose average was lower than that stated by UNSCEAR (2.4 mSv year^{-1}) and ICRP (1.0 mSv year^{-1}) for annual effective doses originating from natural sources [2, 34]. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [2], the average global effective dose from ingesting uranium and thorium series nuclides is 120 µSv year^{-1}, while for ^{40}K it is 170 µSv year^{-1}, ignoring any substantial radiological concerns.

Table 3 shows that the risk of cancer, *R* for adults is based on the total dose of exposure. It is significantly lower than the UNSCEAR cancer risk factor of 8.4×10^{-3} (estimated from UNSCEAR total natural radiation dose of 2.4 mSv year^{-1}) and the cancer risk factor by ICRP of 3.5×10^{-3} (estimated from the recommended level of intake dose 1.0 mSv year^{-1}). Based on Table 3, the average population in one million adults eating sample fish in this study, only about 30 people are estimated to have a risk of death from cancer compared to 3500 people, as predicted by ICRP (1990) and $8^{40}0$ people, as predicted by UNSCEAR (2000) [2, 34, 38].

Cancer risk factor

Table 3. Annual effective dose, *D* and cancer risk factor, *R* due to the consumption of natural radionuclide from the marine fish

Sample	*D* (µSv year^{-1})				*R* ($\times 10^{-5}$)			
	^{232}Th	^{238}U	^{40}K	Total	^{232}Th	^{238}U	^{40}K	Total
FS	2.37	0.57	11.12	14.06	0.83	0.20	3.89	4.92
FC	0.92	0.41	12.76	14.09	0.32	0.14	4.47	4.93
FK	1.71	1.11	11.89	14.71	0.60	0.39	4.16	5.15
Average	1.67	0.70	11.92	14.29	0.59	0.25	4.17	3.00
World average	120	120	170	290	-	-	-	-

Conclusion

Present study shows the concentration of naturally occurring radioactive materials in the widely consumed fish collected from the coastal waters around Peninsular Malaysia. Activity concentrations of 0.06 – 0.33 Bq kg^{-1} for ^{232}Th, 0.11 – 0.48 Bq kg^{-1} for ^{238}U and 23.13 – 43.31 Bq kg^{-1} for ^{40}K in various fish samples agreed with the values previously reported by other researchers and UNSCEAR. The total annual effective dose obtained was in the range of 14.06 – 14.71 µSv year^{-1} and the average value of 14.29 µSv year^{-1}. The estimated cancer risk for adults from the annual effective dose is 3.00×10^{-5}. This value is significantly lower than the UNSCEAR cancer risk factor of 8.4×10^{-3} and the ICRP cancer risk factor of 3.5×10^{-3}. Therefore, it can be concluded that the fish in this study are radiologically safe for the use of nearby residents.

Acknowledgement

Author expresses their sincere gratitude to the Universiti Malaysia Sabah for the financial support (Skim Penyelidikan Lantikan Baharu (SPLB) SLB2203, Universiti Kebangsaan Malaysia and Malaysian Fisheries Development Board (LKIM) for providing infrastructure facilities.

References

1. Broecker, W. S. (1981). Geochemical tracers and ocean circulation in evolution of physical oceanography, B. A. Warren and C. Wunsch, eds. Cambridge, MA: MIT Press.
2. UNSCEAR (United Nations Scientific Committee on the effects of Atomic Radiation). (2008). Sources and effects of Ionizing radiation. Exposures of the public and workers from various sources of radiation. Report to the General Assembly with Scientific Annexes, Annex-B.
3. Amin, Y. M., Mahat, R. H., Nor, R. M., Khandaker, M. U., Takleef, G. H., and Bradley, D. A. (2013). The presence of natural radioactivity and ^{137}Cs in the South China sea bordering Peninsular Malaysia. *Radiation Protection Dosimetry*, 156: 475-480.

4. Khandaker, M. U., Norfadira, B. W., Amin, Y. M., and Bradley, D. A. (2013). Committed effective dose from naturally occurring radionuclides in shellfish. *Radiation Physics and Chemistry*, 88: 1-6.
5. Khandaker, M. U., Olatunji, M. A., Shuib, K. S. K., Hakimi, N. A., Nasir, N. L. M., Asaduzzaman, K., and Bradley, D. A. (2015). Natural radioactivity and effective dose due to the bottom sea and estuaries marine animals in the coastal waters around Peninsular Malaysia. *Radiation Protection Dosimetry*, pp. 1-5.
6. Abbasisiar, F. T., Hosseini, A., and Heravi, F. G. (2004). Determination of uranium isotopes (^{234}U, ^{238}U) and natural uranium (U-nat) in water samples by alpha spectrometry. *Iranian Journal of Radiation Research*, 2: 1-6.
7. Khan, M. F., Benjamin, J., and Godwin, S. W. (2011). Radiotoxicity via intake of marine organisms: exposure and risk assessment in South Indians. *Toxicology and Environmental Chemistry*, 93: 549-564.
8. IAEA (International Atomic Energy Agency). (1998). Inventory of radioactive waste disposals at sea (TECDOC-1105). Access from http://www-pub.iaea.org/books/iaeabooks/5786/Inventory-of-Radioactive-Waste-Disposals-at-Sea.
9. Bogatov, S., Kisselev, V., Sorokovikova, O., and Vysotsky, V. (2009). Radiation consequences of hypothetical accidents associated with transportation of spent nuclear fuel of nuclear submarines aboard floating technical base. *Radioprotection,* 44(5): 159-164.
10. UNSCEAR (United Nations Scientific Committee on the effects of Atomic Radiation). (2000). Source and effects of ionizing radiation. New York: United Nations.
11. Carvalho, F. P., Oliveira, J. M., and Malta, M. M. (2011). Radionuclides in deep-sea fish and other organisms from the North Atlantic Ocean. *ICES Journal of Marine Science*, 68: 333-340.
12. Iyengar, M. A. R. (1990). The environmental behaviour of radium. Technical Report Series, 310, International Atomic Energy Agency, Vienna; Vol. II, pp.59-128.
13. Brown, J. E., Jones, S. R., Saxen, R., Thorring, H., Vives, I., and Battle, J. (2004). Radiation doses to organisms from natural radionuclides. *Journal of Radiological Protection*, 24: A63-A77.
14. Matta, J., Milad, M., Manger, R., and Tosteson, T. (1999). Heavy metals, lipid peroxidation, and cigateratoxicity in the liver of the Caribben barracuda (*Sphyraena barracuda*). *Biological Trace Element Research*, 70: 69-79.
15. Templeton, W., Harrison, F., Knezovich, J., Fisher, N., and Layton, D. (2009). Bioconcentration of radionuclides in marine food-web organism. Battelle Pacific Northwest Laboratories, Richland, WA, 49-61.
16. Aarkrog, A., Baxter, M. S., Bettencourt, A. O., Bojanowski, R., Bologa, A., Charmasson, S., and Cunha, I. (1997). A comparison of doses from ^{137}Cs and ^{210}Po in marine food: a major international study. *Journal of Environmental Radioactivity*, 34(1): 69-90.
17. Narayana, Y., Radhakrishna, A. P., Somashekarappa, H. M., Karunakara, N., Balakrishna, K. M., and Sidappa, K. (1995). Distribution of some natural and artificial radionuclides in the environment of Coastal Karnataka of South India. *Journal of Environmental Radioactivity,* 28: 113-139.
18. Young, A. K., McCubbin, D., and Camplin, W. C. (2002). Natural radionuclides in seafood. Food Standard Agency Report, CEFAS, FSA Project 2002, R 03010.
19. Alam, L., and Mohamed, C. A. R. (2011). Natural Radionclide of ^{210}Po in the edible seafood affected by coal-fired power plant industry in Kapar coastal area of Malaysia. *Environmental Health*, 10: 43.
20. Connan, O., Germain, P., Solier, L., and Gouret, G. (2007). Variations of ^{210}Po and ^{210}Pb in various marine organisms from western English Channel: contribution of ^{210}Po to the radiation dose. *Journal of Environmental Radioactivity*, 97: 168-188.
21. Yasir, M. S., Ab. Majid, A., Ahmad Kabir, N., and Yahya, R. (2008). Kandungan logam berat dan radionuklid tabii dalam ikan, air, tumbuhan dan sedimen di bekas tapak lombong. *Malaysian Journal of Analytical Sciences,* 12(1): 172-178.

22. Rosli, M. N. R., Samat, S. B., Yasir, M. S., and Yusof, M. F. M. (2018). Determination of concentration activity natural radionuclide ^{232}Th, ^{238}U and ^{40}K in fish at the coastal area of Terengganu, Malaysia. *Sains Malaysiana,* 47(9): 2151-2156.
23. Ruth, E. W. (2005). Introduction to ICP-MS. Crustal Geophysics and Geochemistry Science Center, U.S. Geological Survey, pp. 21-52.
24. Warr, S., Rodriguez, G., and Penm, J. (2008). Changing food consumption and imports in Malaysia. Australian Government, Department of Agriculture, Fisheries and Forestry, Canberra, pp. 1-29.
25. ICRP (2012). Compendium of dose coefficients based on ICRP Publication 60: ICRP Publication 119. Oxford: Pergamon Press.
26. IAEA (2004). Radiation, people and the environment: a broad view of ionising radiation, its effects and uses as well as the measures in place to it safely. Vienna: IAEA.
27. Hyde, E. K. (1960). The Radiochemistry of Thorium. Subcommittee on Radiochemistry, National Academy of Sciences-National Research Council. Retrieved from http://www.radiochemistry.org/periodictable/pdf_books/pdf/rc000034.pdf
28. Hong, G. H., Baskaran, M., and Molaroni, S. M. (2011). Anthropogenic and natural radionuclides in caribou and muskoxen in the Western Alaskan Arctic and marine fish in the Aleutian Islands in the first half of 2000. Science of Total Environment, 409: 3638-3648.
29. Narayana, Y., Radhakrishna, A. P., Somashekarappa, H. M., Karunakara, N., Balakrishna, K. M., and Siddappa, K. (1995). Distribution of some natural and artificial radionuclides in the environment of coastal Karnataka of South India. *Journal of Environmental Radioactivity,* 28(2): 113-139.
30. Ademola, J. A. and Ehiedu, S. I. (2010). Radiological analysis of ^{40}K, ^{226}Ra and ^{232}Th in fish, crustaceans and sediment samples from fresh and marine water in oil exploration area of Ondo state, Nigeria. *African Journal of Biomedical Research*, 13: 99-106.
31. Kılıç, Ö., Belivermiş, M., Çotuk, Y., and Topçuoğlu, S. (2014). Radioactivity concentrations in mussel (*Mytilus galloprovincialis*) of Turkish Sea coast and contribution of ^{210}Po to the radiation dose. *Marine Pollution Bulletin,* 80(1-2): 325-329.
32. Samat, S. B., Green, S., and Beddoe, A. H. (1997). The ^{40}K activity of one gram of potassium. *Physics in Medicine and Biology*, 42(2): 407.
33. Patra, A. C., Mohapatra, S., Sahoo, S. K., Lenka, P., Dubey, J. S., Thakur, V. K., ... and Tripathi, R. M. (2014). Assessment of ingestion dose due to radioactivity in selected food matrices and water near Vizag, India. *Journal of Radioanalytical and Nuclear Chemistry*, 300: 903-910.
34. ICRP (1990). Recommendation of the international commission on radiological protection: ICRP Publication 60. Pergamon Press, Oxford.
35. IAEA (2013). Certified reference material for radionuclides in fish flesh sample IAEA-414 (Mixed fish from the Irish Sea and North Sea). Vienna: IAEA.
36. John, P., Margaret, M., Lynne, H., and Fred, M. (2009). Radiological and chemical fact sheets to support health risk analyses for contaminated areas. Argonne National Laboratory, Environmental Science Division: pp. 28-36.
37. Awudu, A., Faanu, A., Darko, E., Emi-Reynolds, G., Adukpo, O., Kpeglo, D., ... and Agyeman, B. (2012). Preliminary studies on ^{226}Ra, ^{228}Ra, ^{228}Th and ^{40}K concentrations in foodstuffs consumed by inhabitants of Accra metropolitan area, Ghana. *Journal of Radioanalytical and Nuclear Chemistry,* 291(3): 635-641.
38. UNSCEAR. (1993). Dose assessment methodologies. United Nations Scientific Committee on the Effects of Atomic Radiation. New York: United Nations, 121-126.