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MARINE POLLUTION AND ECOLOGICAL DEGRADATION

Human health risk assessment due to consumption of dried fish in Chennai, Tamil Nadu, India: a baseline report

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Abstract

The current study sought to determine the levels of radioactivity and heavy metal contamination in 22 dried fish samples collected in Chennai, Tamil Nadu. The study found that there were substantial heavy metals concentrations for Pb, Mn, Cr, Co, and Cd. The concentration of heavy metal Pb being alarmingly high (32.85 to 42.09 mg/kg), followed by Cd (2.18 mg/kg to 3.51 mg/kg) than the permissible limit of WHO (2.17 mg/kg) for Pb and (0.05 mg/kg) for Cd. In terms of radioactivity, the gross alpha activity in the dried fish samples ranged 6.25 ± 0.12 to 48.21 ± 0.11 Bg/kg with an average of 20.35 Bg/kg and with a gross beta activity from 6.48 ± 0.02 to 479.47 ± 0.65 Bg/kg, for an average of 136.83 Bg/kg. The study found that the internal radiation dose that people receive upon consuming the fish species *Sphyraena obtusata*, *Rachycentron canadum*, *Lepidocephalichthys thermalis*, *Synodontidae*, *Carangoides malabaricus*, *Sardina pilchardus*, *Scomberomorus commerson*, *Sillago sihama*, *Gerres subfasciatus*, and *Amblypharyngodon mola* is above the ICRP-recommended limit of less than 1 mSv/year. Annual gonadal dose equivalent (AGDE) and total excessive lifetime cancer risk (ELCR) ranged 0.488 μSv year^{-1} and 0.004 μSv year^{-1} respectively, the values of AGDE being higher than the global average value. The findings of the study indicate that the analyzed dried fish samples are contaminated with Pb and Cd, which shall pose cancer risk to the consumers as a result.

Keywords Alpha activity · Beta activity · Dried fish · Heavy metals · Risk

Introduction

Fisheries and aquatic resources are essential to the nation economically, ecologically, culturally, and esthetically (Bhuiyan et al. 2008; Pandey et al. 2021; Santhanam et al. 2022). India is the 3rd largest fish producer (FAO 2019; Debnath et al. 2022; Plamoottil and Pradeep 2022), with 17% of total catch venturing to drying (Bharda et al. 2017), which is greater than the global average of 2%. (FAO 2018). With a per capita consumption of 9.8 kg compared to the requirement of 13 kg, approximately 35% of Indians eat fish. In the majority of developing countries, fisheries play a substantial part in reducing food and nutrition insecurity for the very poor. The importance of fish to healthy feeding and health is well proven due to its extraordinary nutritious makeup (Gutema and Hailemichael 2021; Koehn et al. 2022). Following agriculture, the fishing sector employs and feeds a sizable portion of India's rural population, particularly the poor. In the Indian state of Tamil Nadu, more than 50% of

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all fish landed is cured before sale and eating (FAO 2006). When compared to global numbers, India has fairly a high total fish catch percentage used for curing (12.5%) (Singh et al. 2014; Deka et al. 2022). The majority of individuals (17%) around the world get their animal protein from seafood (FAO 2016). Live, fresh, or cold fish accounted for 46.9% of all fish products in 2010 that were intended for direct human consumption. Frozen fish came in second at 29.3%, followed by prepared or preserved fish at 14%, and cured fish at 14%. (FAO 2012). Smoke drying is also a process of preserving which is consumed all over the world as protein source (Iko Afé et al. 2020). Toprolong the shelf life of fish, preservation is essential right away (Aniesrani Delfiya et al. 2022; Sanzharova et al. 2021).

Drying or salting is a traditional method in fish processing and one of the oldest ways to preserve fish. Dried fish is a low-cost source of high-quality protein (Mithun et al. 2021). Fish was originally dried only by open sun-drying processes, which are still frequently used in many impoverished nations (Nagwekar et al. 2017) (Table 1). Because of the inexpensive cost of equipment and operation, solar and convection air-drying are being used in commercial manufacturing. (Aniesrani Delfiya et al. 2022; Ariyamuthu et al. 2022; Carciofi et al. 2022). During drying, the moisture

Table 1 Dried fish species with the common name and scientific name

Sample code	Common name	Scientific name	Living behavior	Type of feeding
DF01	Anchovy	*Engraulidae*	Shallow tropical seas	Carnivores (filter feeders)
DF02	Barracuda	*Sphyraenaobtusata*	Open ocean, nearshore coral reefs, seagrass, and mangroves	Carnivores (feed on other fishes)
DF03	Bombay duck	*Harpadonnehereus*	Benthopelagic zone (0–150 m)	Carnivores (zooplankton, fish larva)
DF04	Cobia	*Rachycentron canadum*	Bathypelagic zone (1188 m)	Carnivores (crustacean, squid)
DF05	crescent grunter	*Teraponjarbua*	Shallow coastal water	Carnivores (small fishes, insects, benthic invertebrates)
DF06	Cured Tuna	*Thunnini*	Mesopelagic zone (500–1000 m)	Carnivores (fish, squid, crustacean)
DF07	Hilsa fish	*Tenualosa ilisha*	Epipelagic zone (0–200 m)	Carnivores (phytoplankton with small quantity of zooplankton)
DF08	Malabar anchovy	*Thryssa malabarica*	Epipelagic zone (0–50 m)	Filter feeders
DF09	Indian spiny loach	*Lepidocephalichthysthermalis*	Shallow areas	Substrate feeders (phytoplantons like diatoms and desmids and crustaceans like daphnia and ostracods)
DF10	Indian goat fish	*Parupeneus indicus*	Epipelagic zone (max to 60 m)	Carnivores (small fish, benthic invertebrates, shrimps, Polychete worms, small crabs, small octopus)
DF11	Lizard fish	*Synodontidae*	Mesopelagic zone (upto 396 m)	Carnivores (fish, molluscs, shrimps)
DF12	Marckerel	*Rastrelligerkanagurta*	Shallow coastal water	Planktivores (planktons)
DF13	Malabar trevally	*Carangoides malabaricus*	Epipelagic zone (30–140 m)	Carnivores (crustaceans, small squid, fishes)
DF14	Milk shark	*Rhizoprionodon acutus*	Epipelagic zone (0–200 m)	Carnivores (crustaceans, molluscs, and annelids)
DF15	Northern mackerel scad	*Decapterusrusselli*	Epipelagic zone (not exceeding 100 m)	Planctivores (zooplanktons)
DF16	Sardines	*Sardina pilchardus*	Epipelagic zone(upto 50 m)	Planktivores (zooplanktons)
DF17	Silver scabbardfish	*Lepidopuscaudatus*	Mesopelagic zone (333–620 m)	Carnivores (decapods, fishes, and cephalopods)
DF18	Seer fish	*Scomberomorus commerson*	Shallow water along coastal slope	Carnivores (small fishes and crustaceans)
DF19	Silver whiting fish	*Sillagosihama*	Epipelagic zone (0–30 m)	Carnivores
DF20	Silver belly fish	*Gerres subfasciatus*	Epipelagic zone (0–100 m)	Carnivores (bottem dwelling invertebrates)
DF21	Pink perch	*Synagris japonicus*	Epipelagic zone (upto 188 m)	Carnivores (shrimp, squid, octopus, fishes)
DF22	Mola carplet	*Amblypharyngodon mola*	Epipelagic zone (100 m)	Planktivores (feed on phytoplankton)

level is diminished to roughly 15%, which inhibits autolytic activity and microbiological growth (Nagwekar et al. 2017). The infection of the products by fly and insect larvae during drying and storage, which deteriorates the products before eating, is a key issue linked with sun drying of fish. It normally takes 5 to 7 days for the fish to dry, during which time it becomes significantly polluted (Pravakar et al. 2013; Natarajan et al. 2022). Evidence shows that Middle Eastern and eastern societies deliberately dried food in the scorching heat as early as 12,000 B.C., claims Nummer et al. 2002).

There are specialized sites for the preparation of dried fish in Tamil Nadu's larger fish markets, such as Kasimedu fishing harbor in Chennai. The demand for dried fish is stronger in places like hilly and non-coastal locations, where fresh fish is limited and costly, according to (Immaculate et al. 2013). In Chennai, dried fish is consumed weekly once or twice in people's regular diet, which is about 10% of fresh fish consumption. Similarly, during India's seasonal fishing ban, (Das et al. 2013) discovered a rise in demand for dried fish. Anand (2020) claims that during the Corona pandemic lockdown, when fresh fish was tough to obtain, dried fish was in high demand (Leela et al. 2021). Millions of people rely on the supply side industry of dried fish production for food, income, and employment (Belton et al. 2022). In a review study on the importance of dried fish to food and nutritional security, (Siddhnath et al. 2022) highlighted its high-quality nutrients, including proteins, eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA), as well as the antioxidants and omega-3 benefits of fresh fish. In addition, iodine, zinc, copper, selenium, and calcium are found in it (Shashikanth and Somashekar 2020; Sajeev et al. 2022).

Food can contain radiation from both natural and artificial sources. Examples of natural sources of radiation in food include cosmic radiation and radioactive elements like potassium-40, while artificial sources include radioactive materials used in medical and industrial applications and nuclear weapons testing. The health effects of radiation in food can vary depending on the amount and duration of exposure. Exposure to high levels of radiation can cause radiation sickness, cancer, and other health problems. However, the levels of radiation usually present in food are typically low enough to not pose significant health risks. To minimize potential health risks, regulatory bodies have established guidelines for radiation levels in food, and following good food handling and storage practices can also help reduce exposure (Aladjadjiyan 2022).

Heavy metals' impacts on human health and the environment are of particular interest today, particularly in aquatic food products (El-sayed and Ali 2020; Uluozlu et al. 2007; Mahdi Ahmed et al. 2021; Mukherjee et al. 2022). Heavy metals can accumulate in marine ecosystems such as water, sediments, and fish, and eventually enter the human food chain (Steinhausen et al. 2022). Toxic heavy metal pollution of the natural environment is a worldwide issue. (Sobhanardakani et al. 2018a,b; Sobhanardakani 2017). Metals such as Cu, Fe, Mn, and Zn are essential metals because they play an important role in biological systems, particularly human physiology, whereas non-essential metals such as As, Cd, Cr, Hg, and Pb are toxic even in trace amounts (Sobhanardakani 2017). Toxic metals can easily cause sub-lethal effects or even deaths in local fauna populations due to their propensity to be strongly accumulated and bioconcentrated in sediments and aquatic food chains (Nasrabadi & Bidabadi 2013). Fish are a good subject to study arsenic bioaccumulation in aquatic bodies because of their higher trophic levels and because they are remarkable and common in the human diet (Nasrabadi et al. 2015). As a result, excesses of their concentrations are associated with a variety of negative health effects, including depletion of some essential nutrients in the body, esophagus, and larynx damage, impaired psychosocial behavior, a decrease in immunological defenses, reproductive disorders, and cancer (Davodpour et al. 2019; Tayebi and Sobhanardakani 2020). The accumulation of metals varies greatly between fish species and/or fish tissues. In general, fish can translocate large amounts of toxic heavy metals in their liver, gills, and muscle tissues (Sobhanardakani et al. 2012; 2018a, b); (Sobhanardakani et al. 2012; Sobhanardakani 2017).

Fish have the ability to collect heavy metals in their tissues to levels hundreds of times greater than the concentration of metals in their aqueous medium (Mukherjee et al. 2022). Contamination of heavy metal in fish has become a major global issue, due to the risk posed by consuming those fish (Rahman et al. 2012). At some exposure and absorption level, all heavy metals are potentially hazardous to the majority of species (Firdous et al. 2021; Melila et al. 2022). Histamine profile of the dried fish collected from the local markets was also examined in the preceding studies, where the values exceeded the regulatory limit (Amascual et al. 2020). However, certain radionuclides act cautiously and continue to be water-soluble, while others are immiscible, attach to particles, and are inevitably transported to marine sediments (IAEA 2005; Duong Van et al. 2020). These radionuclides that accumulate in marine organisms, pass on further to people upon ingestion (Manav et al. 2016; Singh et al. 2021). Studies conducted so far in determining the radioactivity level have focused only on fresh fish (Duong Van et al. 2020, 2022; Nandhakumari et al. 2014). The radioactivity levels in fish after it has undergone the drying process and the subsequent dose that is received by the consumers upon ingestion are lacking, making the present study to be novel in the entire world. As a result, the primary objective of the current study was designed as follows: (i) to build a baseline data on the radioactivity profile of commercially available dried fish samples through gross alpha and gross beta activity estimation, (ii) calculate the annual effective dose and other radiological risks to consumers, and (iii) assess the heavy metals concentration and risks (both carcinogenic and non-carcinogenic risk) associated with dry fish consumption.

Materials and methods

Collection and processing of dried fish samples

Twenty-two species of dried fish were collected from wholesale markets in and around Chennai, Tamil Nadu, India, which represent the most regularly consumed species in India, namely, Anchovy (*Engraulidae*), Barracuda (*Sphyraena obtusata*), Bombay duck (*Harpadon nehereus*), Cobia (*Rachycentron canadum*), crescent grunter (*Terapon jarbua*), Cured Tuna (*Thunnini*), Flathead grey mullet (*Mugil cephalus*), Gautama thryssa (*Thryssa malabarica*), Indian spiny loach (*Lepidocephalichthys thermalis*), Indian goat fish (*Parupeneus indicus*), Lizard fish (*Synodontidae*), Marckerel (*Rastrelliger kanagurta*), Malabar trevally (*Carangoides malabaricus*), Milk shark (*Rhizoprionodon acutus*), Northern mackerel scad (*Decapterus russelli*), Sardines (*Sardina pilchardus*), Silver scabbardfish (*Lepidopus caudatus*), Seer fish (*Scomberomorus commerson*), Silver whiting fish (*Sillago sihama*), Silver belly fish (*Gerres subfasciatus*), Red snapper (*Lutjanus campechanus*), and Riffle minnow (*Phenacobius catostomus*). The samples were air dried and kept in hot air oven for 150 °C for 2 h. Then, the samples were milled to powder form and sieved to uniform grain size for determining the radioactivity content.

Estimation of gross activity of alpha (α) and beta (β) and associated radiological risk

Gross α and β activity in the samples were counted using alpha and beta counters. Low background beta counter (Nucleonix, Model type: LB615), with plastic scintillator detector and Photomultiplier tube (PMT) was used for the counting of beta emitters. Alpha radiation counting system (Nucleonix, model type: RC605A), equipped with ZnS (Ag) Screen covered with Aluminized mylar foil detector material and photomultiplier tube was used for the counting of alpha emitters. The alpha counter was calibrated with Am^{241} standard source, electro deposited on the SS planchette (typical activity in the range of 3000-5000dpm). The beta counter was calibrated with Sr^{90}-Y^{90} standard source (with 1,11,000 dpm), both the standard sources provided by BARC, Department of Atomic energy, India. Using these reference sources, the counters were calibrated on a regular basis to maintain an efficiency of up to 35% in beta and 23% in alpha, respectively. The sample was spread uniformly in planchettes of alpha and beta counters separately, for a period of 3600 s for 3 iterations to obtain the mean values. The total gross α and β activities measurements were obtained after subtracting the count rate of the samples from the background using the following formula:

$$\text{Activity} = (\text{net CPS}/\text{efficiency} \times \text{ weight of the sample}) \times 100$$

where

$$\text{net CPS} = (\text{total count} - \text{background})/3600,$$
$$\text{efficiency} = \text{CPS}/\text{DPS}$$

CPS count per second

DPS disintegration per second

According to Duong Van et al. (2020) and Agbalagba et al. (2021), using the following formula, the annual committed effective dose received by an adult due to consumption of seafood was estimated, using the following formula:

$$\text{DRr} = \text{Gr} \times \text{CIr} \times \text{DCr}$$

where

DRr yearly effective dose (μSv/year),

Gr gross alpha or gross Beta activity (mBq/l),

CIr amount of seafood ingested per year (kg),

DCr dose conversion coefficient (Sv/Bq).

Adults consume an average of 9.83 kg of fish per year, as reported by the Tamilnadu fisheries department. The annual effective dose were calculated using the annual dose conversion factors of various radionuclide sources were as follows: $^{238}\text{U} = 4.5 \times 10^{-8}$ Sv/Bq, $^{235}\text{U} = 4.7 \times 10^{-8}$ Sv/Bq, $^{234}\text{U} = 4.9 \times 10^{-8}$ Sv/Bq, $^{226}\text{Ra} = 2.8 \times 10^{-7}$ Sv/Bq, $^{210}\text{Po} = 1.2 \times 10^{-6}$ Sv/Bq, $^{210}\text{Pb} = 6.9 \times 10^{-7}$ Sv/Bq (WHO 2017), $^{214}\text{Bi} = 1.1 \times 10^{-10}$, $^{90}\text{Sr} = 2.8 \times 10^{-8}$, $^{137}\text{Cs} = 1.3 \times 10^{-8}$and ^{40} $\text{K} = 6.2 \times 10^{-9}$ Sv/Bq (ICRP 2012). The radiological risk hazards such as annual gonadal dose equivalent (AGDE) and excessive lifetime cancer risk (ELCR) was evaluated following the protocol of (Agbalagba et al. 2021).

Assessment of heavy metal concentration and health risk hazard indices in dried fish

The experiment of heavy metal analysis was carried out using Atomic Absorption Spectrophotometer (Perkin Elmer-PinAAcle 900AA), following the protocol of Ranasinghe et al. (2016). A qualitative assessment of possible non-carcinogenic [target hazard quotient (THQ), hazard index (HI)] and carcinogenic [lifetime cancer risk (LCR)] risk effects of heavy metals on humans via oral exposure to the toxic elements based on daily fish consumption was conducted using the methodology of Edosomwan et al. (2019) , (FAO 2005).

$$\mathrm{THQ} = \frac{\mathrm{EF} \times \mathrm{ED} \times \mathrm{FIR} \times \mathrm{C}}{RfD \times WAB \times TA} \times 10^{-3}$$

$$\begin{aligned}\mathrm{HI} =& \mathrm{THQ}_{(\mathrm{Zn})} + \mathrm{THQ}_{(\mathrm{Cu})} + \mathrm{THQ}_{(\mathrm{Pb})} \\ &+ \mathrm{THQ}_{(\mathrm{Fe})} + \mathrm{THQ}_{(\mathrm{Mn})} + \mathrm{THQ}_{(\mathrm{Cd})} \\ &+ \mathrm{THQ}_{(\mathrm{Co})} + \mathrm{THQ}_{(\mathrm{Cr})} + \mathrm{THQ}_{(\mathrm{Ni})}\end{aligned}$$

$$\mathrm{LCR} = \frac{EF \times ED \times FIR \times C \times CSF}{WAB \times TA} \times 10^{-3}$$

where the parameters used in the above equations are as follows:

EF, exposure frequency (365 days/year); ED, average lifetime (70 years); FIR, fish Ingestion rate (2.6 g per day for a person). C, metal concentration (mg/kg); RfD, reference oral dose calculated with body weight and intake per day as suggested by (USEPA 2010) for the elements (1×10^{-3} for Cd, 4×10^{-2} for Cu, 3×10^{-1} for Zn, 4×10^{-3} for Pb, 1.5 for Cr, 2×10^{-2} for Co and Ni, 7×10^{-1} for Fe, 1.4×10^{-1} for Mn); WAB, average body weight of adults who consume (67 kg); TA, mean exposure time (365 days/year × ED).

Statistical analysis

The results of gross α and β activity in the dried fish samples are expressed as mean ± SD. The multipanel scatter plot figures of heavy metal concentration were computed using Origin software version 2018. The correlation and regression analysis, PCA using varimax rotation and one-sample *t*-test were performed using SPSS software version 24.

Result and discussion

Gross alpha and beta activity

Table 2 represents the gross alpha (α) and beta (β) activity for dried fish samples that are widely consumed in Chennai, Tamil Nadu. Gross α values ranged from a minimum of

Table 2 Gross alpha and gross beta activity in dried fish samples (**BDL*, below detectable limit)

Common name	Scientific name	Total activity (Bq/kg)	
Gross alpha	Gross beta		
Anchovy	*Engraulidae*	17.93 ± 0.46	83.50 ± 0.43
Barracuda	*Sphyraena obtusata*	BDL	218.89 ± 0.59
Bombay duck	*Harpadon nehereus*	BDL	101.26 ± 0.81
Cobia	*Rachycentron canadum*	12.28 ± 0.01	211.74 ± 0.78
crescent grunter	*Terapon jarbua*	17.93 ± 0.46	84.62 ± 0.51
Cured Tuna	*Thunnini*	BDL	69.86 ± 0.14
Hilsa fish	*Tenualosa ilisha*	24.10 ± 0.31	64.85 ± 0.30
Malabar anchovy	*Thryssa malabarica*	6.27 ± 0.11	16.27 ± 0.08
Indian spiny loach	*Lepidocephalichthys thermalis*	36.43 ± 0.18	273.88 ± 0.38
Indian goat fish	*Parupeneus indicus*	12.28 ± 0.01	94.52 ± 0.48
Lizard fish	*Synodontidae*	18.49 ± 0.11	121.71 ± 0.84
Marckerel	*Rastrelliger kanagurta*	BDL	46.38 ± 0.35
Malabar trevally	*Carangoides malabaricus*	48.21 ± 0.11	138.31 ± 0.61
Milk shark	*Rhizoprionodon acutus*	24.17 ± 0.33	6.48 ± 0.02
Northern mackerel scad	*Decapterus russelli*	6.25 ± 0.12	70.09 ± 0.55
Sardines	*Sardina pilchardus*	BDL	208.18 ± 0.30
Silver scabbardfish	*Lepidopus caudatus*	BDL	44.57 ± 0.83
Seer fish	*Scomberomorus commerson*	24.17 ± 0.33	479.47 ± 0.65
Silver whiting fish	*Sillago sihama*	BDL	90.78 ± 0.16
Silver belly fish	*Gerres subfasciatus*	18.35 ± 0.02	198.76 ± 0.61
Pink perch	*Synagris japonicus*	BDL	122.59 ± 0.30
Mola carplet	*Amblypharyngodon mola*	17.93 ± 0.46	133.31 ± 0.21
Minimum		6.25 ± 0.12	6.48 ± 0.02
Maximum		48.21 ± 0.11	479.47 ± 0.65
Average		20.36	136.84

Table 3 Annual effective dose (µSv/y) of radiation source in dry fish for adults

Scientific name	Annual effective dose µSv/year											
Alpha emitters					Beta emitters					Total		
U238	U235	U234	Ra226	Po210	Pb210	K40	Bi214	Sr90	Cs137	µSv/year	msv/year	
Engraulidae	7.93 ± 0.20	8.28 ± 0.21	8.63 ± 0.22	49.35 ± 1.28	211.54 ± 5.50	566.40 ± 2.94	5.08 ± 0.02	0.09 ± 0.00	22.98 ± 0.11	10.67 ± 0.05	890.95 ± 10.48	0.89095
Sphyraena obtusata	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	1484.72 ± 4.02	13.34 ± 0.03	0.23 ± 0.00	60.24 ± 0.16	27.97 ± 0.07	1586.5 ± 4.21	1.5865
Harpadon nehereus	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	686.81 ± 5.51	6.17 ± 0.04	0.10 ± 0.00	27.87 ± 0.22	12.94 ± 0.10	733.89 ± 5.76	0.7338
Rachycentron canadum	5.43 ± 0.0053	5.67 ± 0.0055	5.91 ± 0.00	33.82 ± 0.03	144.94 ± 0.14	1436.17 ± 5.33	12.90 ± 0.04	0.22 ± 0.00	58.27 ± 0.21	27.05 ± 0.10	1730.38 ± 5.75	1.73038
Terapon jarbua	7.93 ± 0.20	8.28 ± 0.21	8.63 ± 0.22	49.35 ± 1.28	211.54 ± 5.50	573.96 ± 3.52	5.15 ± 0.03	0.09 ± 0.00	23.29 ± 0.14	10.81 ± 0.06	899.03 ± 11.1	0.89903
Thunnini	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	473.85 ± 1.00	4.25 ± 0.00	0.07 ± 0.00	19.22 ± 0.04	8.92 ± 0.01	506.31 ± 1.04	0.50631
Tenualosa ilisha	10.66 ± 0.13	11.13 ± 0.14	11.61 ± 0.15	66.35 ± 0.85	284.39 ± 3.67	439.89 ± 2.03	3.95 ± 0.01	0.07 ± 0.00	17.85 ± 0.08	8.28 ± 0.03	854.18 ± 7.06	0.85418
Thryssa malabarica	2.77 ± 0.05	2.90 ± 0.05	3.02 ± 0.05	17.27 ± 0.31	74.04 ± 1.33	110.40 ± 0.55	0.99 ± 0.00	0.01 ± 8.92	4.48 ± 0.02	2.08 ± 0.01	217.96 ± 11.28	0.21796
Lepidocephalichthys thermalis	16.11 ± 0.07	16.83 ± 0.08	17.54 ± 0.08	100.27 ± 0.49	429.73 ± 2.13	1857.67 ± 2.63	16.69 ± 0.02	0.29 ± 0.00	75.38 ± 0.10	34.99 ± 0.04	2565.5 ± 5.6	2.5655
Parupeneus indicus	5.43 ± 0.00	5.67 ± 0.0055	5.91 ± 0.00	33.82 ± 0.03	144.94 ± 0.14	641.11 ± 3.28	5.76 ± 0.02	0.10 ± 0.00	26.01 ± 0.13	12.07 ± 0.06	880.82 ± 3.60	0.88082
Synodontidae	8.18 ± 0.05	8.54 ± 0.05	8.90 ± 0.05	50.90 ± 0.31	218.16 ± 1.34	825.57 ± 5.70	7.41 ± 0.05	0.13 ± 0.00	33.50 ± 0.23	15.55 ± 0.10	1176.84 ± 7.78	1.17684
Rastrelliger kanagurta	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	314.62 ± 2.38	2.82 ± 0.02	0.05 ± 0.00	12.76 ± 0.09	5.92 ± 0.04	336.17 ± 2.49	0.33617
Carangoides malabaricus	21.32 ± 0.05	22.27 ± 0.05	23.22 ± 0.05	132.69 ± 0.31	568.70 ± 1.34	938.13 ± 4.19	8.42 ± 0.03	0.14 ± 0.00	38.06 ± 0.17	17.67 ± 0.07	1770.62 ± 6.19	1.77062
Rhizoprionodon acutus	10.69 ± 0.14	11.16 ± 0.15	11.64 ± 0.16	66.54 ± 0.93	285.18 ± 3.99	43.95 ± 0.13	0.39 ± 0.00	0.007 ± 2.16	1.78 ± 0.00	0.82 ± 0.00	432.15 ± 7.66	0.432157
Decapterus russelli	2.76 ± 0.05	2.89 ± 0.05	3.01 ± 0.06	17.22 ± 0.35	73.80 ± 1.50	475.44 ± 3.79	4.27 ± 0.03	0.07 ± 0.00	19.29 ± 0.15	8.95 ± 0.07	607.7 ± 5.98	0.6077
Sardina pilchardus	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	1412.07 ± 2.05	12.68 ± 0.01	0.22 ± 0.00	57.30 ± 0.08	26.60 ± 0.03	1508.87 ± 2.14	1.50887
Lepidopus caudatus	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	302.35 ± 5.69	2.71 ± 0.05	0.04 ± 0.00	12.26 ± 0.23	5.69 ± 0.10	323.05 ± 5.97	0.32305
Scomberomorus commerson	10.69 ± 0.14	11.16 ± 0.15	11.64 ± 0.16	66.54 ± 0.93	285.18 ± 3.99	941.98 ± 1.87	8.46 ± 0.01	0.15 ± 0.00	38.22 ± 0.07	17.74 ± 0.03	1391.76 ± 7.32	1.39176
Sillago sihama	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	1488.23 ± 3.93	13.37 ± 0.03	0.23 ± 0.00	60.39 ± 0.15	28.03 ± 0.07	1590.25 ± 4.11	1.59025
Gerres subfasciatus	8.06 ± 0.01	8.42 ± 0.01	8.78 ± 0.01	50.19 ± 0.08	215.11 ± 0.37	1348.18 ± 4.15	12.11 ± 0.03	0.21 ± 0.00	54.70 ± 0.16	25.40 ± 0.07	1731.16 ± 4.82	1.73116
Synagris japonicus	0 ± 0	0 ± 0	0 ± 0	0 ± 0	0 ± 0	831.52 ± 2.05	7.47 ± 0.01	0.13 ± 0.00	33.74 ± 0.08	15.66 ± 0.03	888.52 ± 2.14	0.88852
Amblypharyngodon mola	7.93 ± 0.20	8.28 ± 0.21	8.63 ± 0.22	49.35 ± 1.28	211.54 ± 5.50	904.24 ± 1.44	8.12 ± 0.01	0.14 ± 0.00	36.69 ± 0.05	17.03 ± 0.02	1251.95 ± 8.91	1.25195
Average	8.99	9.39	9.79	55.97	239.91	922.46	8.28	0.14	37.42	17.37	1085.20	1.09

6.25 ± 0.12 Bq/kg in *Decapterus russelli* (DF15) to a maximum of 48.21 ± 0.11 Bq/kg in *Carangoides malabaricus* (DF13), with an average of 20.36 Bq/kg. For gross beta, the activity ranged from 6.48 ± 0.02 Bg/kg in *Rhizoprionodon acutus* (DF14) to 479.47 ± 0.65 Bg/kg in *Scomberomorus commerson* (DF18) Bg/kg, with an average of 136.83 Bg/kg. Gross beta activity for all samples of dried fish were greater than gross alpha activity. The gross alpha activity in dried fish species *Sphyraena obtusata*, *Harpadon nehereus*, *Thunnini*, *Rastrelliger kanagurta*, *Sardina pilchardus*, *Lepidopus caudatus*, *Sillago sihama*, and *Synagris japonicus* were below the detectable limit. The source of radiation in fish species has the possibility to have come from environmental sources such as soil and water, or from industrial sources such as nuclear power plants or other radioactive facilities. Additionally, some fish species may naturally contain small amounts of radioactive substances such as potassium-40, which could contribute to the overall radiation level in the fish.

However, in the scenario of dried fish, in addition to the aforementioned environmental factors, techniques used in preservation such as cleaning, salting, drying, and packaging would have also contributed to the radioactivity tested. The process of drying can cause changes in the composition of the fish, potentially altering its radiation levels and contamination sources. Moreover, the storage and handling of the dried fish can also affect its contamination levels.

The findings of our study are coherent with those of Duong Van et al. (2022) and Duong Van et al. (2020), where they determined gross α and β activity in fresh fish of Vietnam with an observed range of (73–162 Bq/kg for alpha and 65–282 Bq/kg for beta). However, the gross α and β concentrations of *Thunini* (Cured Tuna) were determined as below 61.0 ± 6.8 Bq/kg and 65.5 ± 3.4 Bq/kg, respectively, which was greater than the value we discovered in our investigation. Results of our study were also in concordance to the results of Manav et al. (2016). Moreover, a study conducted in southeast coast of India, Tuticorin, indicated that ^{210}Po concentration in dried fish samples ranged from 1.45 ± 0.82 to 559.23 ± 5.45 Bq /kg (Carol and Wesley 2013).

AED and radiological risk parameters

Annual effective dosage equivalent for alpha emitters and beta emitters with dose conversion factors for ^{238}U, ^{235}U, ^{234}U, ^{226}Ra, ^{210}Po, ^{210}Pb, ^{40} K, ^{214}Bi, ^{90}Sr, and ^{137}Cs is depicted in Table 3. The contribution of alpha and beta emitters to the annual effective dose estimated is in the following descending order as follows: $^{210}\text{Pb} > {}^{210}\text{Po} > {}^{226}\text{Ra} > {}^{90}\text{Sr} > {}^{137}\text{Cs} > {}^{234}\text{U} > {}^{235}\text{U} > {}^{238}\text{U} > {}^{40}\text{K} > {}^{214}\text{Bi}$. According to the estimated results, ^{210}Po corresponds to the highest incidence of activity to the annual effective dose (AED) among alpha emitters, which ranges from 73.80 ± 1.50 to 568.70 ± 1.34 μSv year^{-1} with an average of 239.91 μSv year^{-1}. In contrast, ^{238}U produces the lowest fraction of activity, which ranges from 2.89 ± 0.05 to 22.27 ± 0.05 μSv year^{-1}. However, the largest fraction of AED due to beta emitters was reported in ^{210}Pb, ranging from 43.95 ± 0.13 to 1857.67 ± 2.63 μSv year^{-1}, with a mean value of 922.46 μSv year^{-1}, while ^{214}Bi contributes the least proportion, ranging from 0.07 ± 0.00 to 0.29 ± 0.00 μSv year^{-1}, for the mean value of 0.14 μSv year^{-1}.

The average annual effective dose (AED) for the present study is 1085 μSv year^{-1} that is 1.09 mSv year^{-1}. Among 22 dried fish samples, AED values of the following 10 dried fish, including *Sphyraena obtusata*, *Rachycentron canadum*, *Lepidocephalichthys thermalis*, *Synodontidae*, *Carangoides malabaricus*, *Sardina pilchardus*, *Scomberomorus commerson*, *Sillago sihama*, *Gerres subfasciatus*, and *Amblypharyngodon mola*, were observed to be above the permissible limit of 1 mSv year^{-1}. Similar study carried out by Duong Van et al. (2020 and 2022) in marine and freshwater regions of Vietnam resulted in ACED values to be within the permissible limits and lower than the current study. Study by Manav et al. (2016) reported the annual effective ingestion dose from the fish of turkey to range from 0.011 to 1.169 μSv y^{-1}, being lower than the permissible limits and lower than the value of our present study. The annual gonadal dose equivalent (AGDE) for the current study was found to be 0.488 μSv year^{-1}, which is higher than the world average value of 0.3 μSv year^{-1} (Table 4). However, the total excessive lifetime cancer risk falls around 0.004 μSv year^{-1}, being lower than the recommended limit of 0.29 μSv year^{-1} as set by (WHO 2004).

Heavy metal analysis

The average of Heavy metal concentration were listed as following order for the dried fish species (Fig. 1):

Fe > Zn > Pb > Ni > Mn > Cr > Co > Cu > Cd

Among them, the heavy metal concentrations such as Pb, Mn, Cr, Co, and Cd were discovered to be higher than the FAO 1983 permissible limits. The concentration of Pb (32.85–42.09 mg/kg), Co (2.95–9.55 mg/kg), and Cd (2.18–3.51 mg/kg) in the current study, being above the recommended limit of 2.17 mg/kg, 1.13 mg/kg, and 0.05 mg/kg respectively, in all fish species. The everyday consumption of too much of these metals may cause neurological and psychological problems (Rakib et al. 2021). *Scomberomorus commerson* (DF18) shows the highest concentration of Pb and least most concentration of all other metals Fe, Zn, Cd, Cr, Co, Mn, Cu, and Ni, whereas Parupeneus *indicus* (DF10) shows the highest concentration of Cd and Co. When these species are ingested, a danger of Pb toxicity or poisoning exists (Edosomwan et al. 2019). In addition, prolonged lead

Table 4 Radiological risk parameters

Scientific name	Annual gonadal dose equivalent (AGDE) (mSv/year)	Excessive lifetime cancer risk (ELCR) (mSv/year)
Engraulidae	0.4009	0.0031
Sphyraena obtusata	0.7139	0.0055
Harpadon nehereus	0.3298	0.0025
Rachycentron canadum	0.7786	0.0060
Terapon jarbua	0.4045	0.0031
Thunnini	0.2278	0.0017
Tenualosa ilisha	0.3843	0.0029
Thryssa malabarica	0.0980	0.0007
Lepidocephalichthys thermalis	1.1544	0.0089
Parupeneus indicus	0.3963	0.0030
Synodontidae	0.5295	0.0041
Rastrelliger kanagurta	0.1512	0.0011
Carangoides malabaricus	0.7967	0.0061
Rhizoprionodon acutus	0.1944	0.0015
Decapterus russelli	0.2734	0.0021
Sardina pilchardus	0.6789	0.0052
Lepidopus caudatus	0.1453	0.0011
Scomberomorus commerson	0.6262	0.0048
Sillago sihama	0.7156	0.0055
Gerres subfasciatus	0.7790	0.0060
Synagris japonicus	0.3998	0.0031
Amblypharyngodon mola	0.5633	0.0043
Average	0.4883	0.0037

exposure can result in unconsciousness, mental disability, and even death (Al-Busaidi et al. 2011).

Mn concentration ranged from 3.99 to 34.16 mg/kg in *Scomberomorus commerson* (DF18) and *Gerres subfasciatus* (DF20) respectively, except *Sphyraenaobtusata* (DF02), *Thunnini* (DF06), and *Scomberomorus commerson* (DF18); all other dried fish species were above the recommended limit of 4.35 mg/kg. Cr content had a range of minimum of 2.27 mg/kg in *Scomberomorus commerson* (DF18) and maximum of 37.86 mg/kg in *Synagris japonicus* (DF21). Among 22 species, 13 species were above the permissible limit of 0.65–4.35 mg/kg, such as *Harpadon nehereus* (DF03), *Thunnini* (DF06), *Tenualosa ilisha* (DF07), *Parupeneus indicus* (DF10), *Synodontidae* (DF11), *Rastrelliger kanagurta* (DF12), *Carangoides malabaricus* (DF13), *Rhizoprionodon acutus* (DF14), *Decapterus russelli (DF15)*, *Lepidopuscaudatus* (DF17), *Gerres subfasciatus* (DF20), *Synagris japonicus* (DF21), and *Amblypharyngodon mola* (DF22). Co and Cd have the maximum values of 9.55 mg/kg and 3.51 mg/kg in *Parupeneus indicus* (DF10) and the minimum of 2.95 and 2.18 mg/kg in *Scomberomorus commerson* (DF18) with the average of 5.62 and 2.89 mg/kg which is higher than the permissible limit from WHO, FAO as 0.17–1.13 mg/kg and 0.5 mg/kg. Previous studies (Al-Busaidi et al. 2011; Ahmad et al. 2010) conclude that cadmium harms the kidney and causes chronic poisoning symptoms include tumors, hepatic dysfunction, hypertension, and diminished kidney function. Excess magnesium leads to muscle paralysis, hyperventilation, and coma. Other metals including chromium, zinc, and copper can cause serious kidney lesions, nephritis, and anuria (Ahmad et al. 2010).

A review of the available research on heavy metal levels in fresh fish reveals, heavy metal accumulation in selected fish species in India shows the mean concentration of 0.02–0.40 mg/kg for Pb, 23.1–0.22 mg/kg for Cr, and 0.10–31.73 mg/kg for Zn; all of these values are lower than those found in the current study (Akila et al. 2022). Similarly, in China (Jiang et al. 2022), the heavy metal concentration values of fresh fish are as follows: Cr 0.68–4.64 mg/kg, Fe 1.78–11.29 mg/kg, Ni 0.25–1.75 mg/kg, Cu 0.41–1.43 mg/kg, Zn 13.76–38.38 mg/kg, Cd 0.001–0.019 mg/kg, and Pb 0.042–0.240 mg/kg; and in Bulgaria, Makedonski et al. (2017) demonstrated study in fresh fish heavy metal concentration resulted as Cd 0.008–0.031 mg/kg, Zn 5.2–11 mg/kg, Cu 0.34–1.4 mg/kg, and Pb 0.06–0.08 mg/kg shows the concentration values of heavy metals are lower than the current study. Some reports, such as Koker's 2000 report, found accumulations of heavy metals that exceeded governmental guidelines. According to this study, dried fish contains more heavy metals concentration than fresh fish.

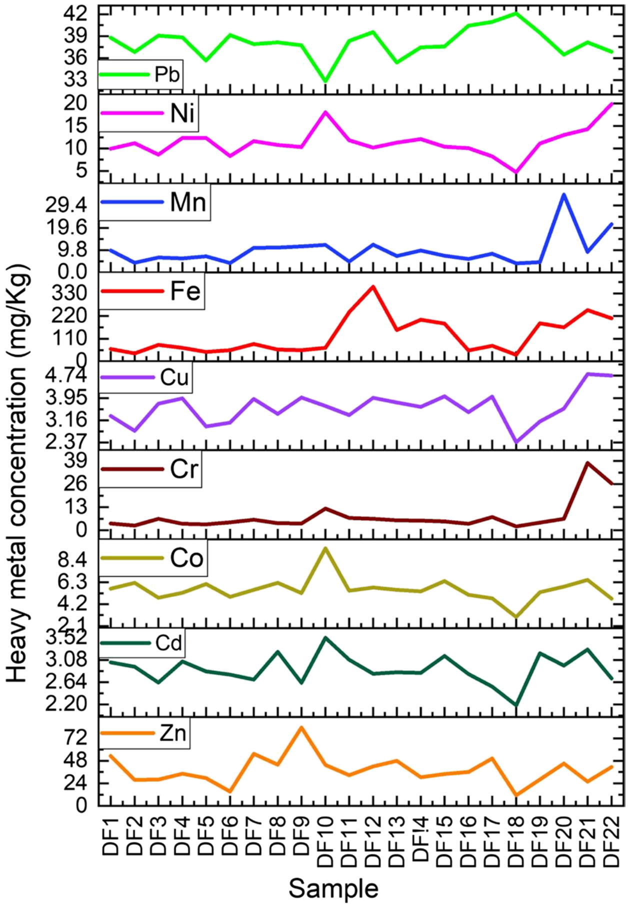


Fig. 1 Heavy metal concentration in dried fish samples consumed in Chennai

Results of the present study are in congruence to the results of Bashir et al. (2013) and Praveena and Lin (2015) which is lower than the current study and Rahman et al. (2012) shows the concentration of fish of Zn, Mn, and Cu shows high than the current study and Ni, Cd, Cr, Pb concentration of previous study were less than the current study. According to Nagwekar et al. (2017), the lead concentration of the chosen salt fish is lower than it is in the current investigation. Previous studies have demonstrated that prolonged, low-level exposure to heavy metals can have several negative health impacts (Elias et al. 2014). The fresh fish was infrequently cleaned, leading to potential contamination, while the dried fish sold in marketplaces was subject to air deposition. In comparison to fresh fish, the analyzed samples of salted fish generally had greater amounts of mercury and lead. These findings were likely caused by the use of impure salts during the salting process (Yosef and Gomaa, 2011; Manav et al. 2016; Elrais et al. 2018; Yilmaz et al. 2010). Despite the evidence suggesting there was a low chance of a health danger, all salted fish tests had some level of heavy metal contamination.

Non-carcinogenic and carcinogenic health risks

Table 5 shows the non-carcinogenic risks, notably the target hazard quotient (THQ) and hazard index (HI), as well as the carcinogenic risks. In general, THQ and HI > 1 indicate that single components are likely to have negative health effects. The hazardous index demonstrates that the value of each heavy metal in all dried fish samples, as presented in Table 5 is lesser than 1 which indicates that there are no non-carcinogenic risks to the consumers. Due to the lack of a gradient feature for the other metals analyzed or the non-detection of other carcinogenic metals, only Cd and Pb were evaluated in the various fish species in terms of carcinogenic risk. The permissible range for carcinogens is between 10^{-6} and 10^{-4} as per the standards of (USEPA 2010). According to the obtained data for the present study, the estimated TR values (carcinogenic risk) for Cd are higher than the permissible limit for all the dried fish species, with Pb values being slightly higher when considered 10^{-5} as a benchmark. This highlights, that there is cancer associated risk for the studied dried fish sample, due to the contamination of heavy metals Cd and Pb.

Correlation, PCA, and "one-sample t-test" analysis

According to the Correlation study between the evaluated heavy metals (Table 6), a positive correlation was observed between Cd-Co and Cr-Cu. The heavy metal Ni correlated significantly with Cd, Co, Cr, and Cu. On the other hand, the heavy metal Pb exhibited a negative correlation with Cd, Co, and Ni. The high correlation coefficients between these heavy metals suggest that they migrate and change under similar physicochemical conditions in the environment. Low or negative correlation coefficients, on the other hand, may point to many causes that are connected to natural or geogenic processes (Qing-ping et al. 2016; Weissmannová et al. 2019; Štofejová et al. 2021). PCA was applied to the contents of heavy metals for the 22 dried fish samples, using varimax rotation to trace the origin of heavy metals (Fig. 2). To check the feasibility of PCA analysis KMO and Bartlett test were done which results in the values of KMO is 0.65 and Bartlett significance value < 0.01, hence the calculated PCA is valid. 77.28% of the total variance is explained by the first three PCA components. The greatest loadings on Cd, Co, Ni, and Pb are displayed by PC1, which may explain 42.86% of the entire variance. With maximum loadings on Cr, Cu, Fe, and Mn, PC2 can explain the overall variance of 19.68%, while PC3 can explain the total variance of 14.73% with maximum loadings on Zn, Mn, and Pb. The presence of Cd, Co, Cu, and Cr is due to human sources of industrial waste, contamination from fish markets. The presence of Zn, Fe, Mn, and Ni are from the natural sources (river and marine waters) and due to atmospheric precipitation

Table 5 Risk hazard indices due to heavy metal concentrations in the dried fish samples

	Total hazard quotient									TR lead	TR cadmium	HI
Sample	Zinc	Cadmium	Cobalt	Chromium	Copper	Iron	Manganese	Nickel	Lead			
DF1	0.104	0.039	0.011	1.01E-04	0.003	0.337	0.003	0.019	0.376	1.28E-05	7.41E-04	0.46
DF2	0.054	0.038	0.012	6.94E-05	0.003	0.216	0.001	0.022	0.357	1.21E-05	7.19E-04	0.44
DF3	0.055	0.034	0.009	1.65E-04	0.004	0.439	0.002	0.017	0.379	1.29E-05	6.44E-04	0.45
DF4	0.066	0.039	0.010	9.40E-05	0.004	0.363	0.002	0.024	0.377	1.28E-05	7.45E-04	0.46
DF5	0.058	0.037	0.012	8.67E-05	0.003	0.254	0.002	0.024	0.346	1.18E-05	6.97E-04	0.43
DF6	0.030	0.036	0.009	1.15E-04	0.003	0.303	0.001	0.016	0.380	1.29E-05	6.82E-04	0.45
DF7	0.108	0.035	0.011	1.55E-04	0.004	0.470	0.003	0.023	0.368	1.25E-05	6.58E-04	0.45
DF8	0.085	0.042	0.012	1.05E-04	0.003	0.321	0.003	0.021	0.370	1.26E-05	7.92E-04	0.46
DF9	0.162	0.034	0.010	1.01E-04	0.004	0.302	0.003	0.020	0.366	1.25E-05	6.43E-04	0.45
DF10	0.084	0.045	0.019	3.16E-04	0.004	0.364	0.003	0.035	0.319	1.08E-05	8.60E-04	0.43
DF11	0.064	0.040	0.011	1.81E-04	0.003	1.326	0.001	0.023	0.372	1.27E-05	7.53E-04	0.47
DF12	0.081	0.036	0.011	1.67E-04	0.004	2.008	0.003	0.020	0.384	1.30E-05	6.87E-04	0.48
DF13	0.093	0.037	0.011	1.47E-04	0.004	0.846	0.002	0.022	0.343	1.17E-05	6.93E-04	0.43
DF14	0.059	0.037	0.011	1.40E-04	0.004	1.119	0.003	0.023	0.363	1.24E-05	6.90E-04	0.46
DF15	0.066	0.041	0.012	1.29E-04	0.004	1.021	0.002	0.020	0.365	1.24E-05	7.71E-04	0.46
DF16	0.070	0.036	0.010	9.68E-05	0.003	0.291	0.002	0.019	0.392	1.33E-05	6.84E-04	0.47
DF17	0.098	0.033	0.009	1.93E-04	0.004	0.421	0.002	0.016	0.397	1.35E-05	6.23E-04	0.47
DF18	0.022	0.028	0.006	5.89E-05	0.002	0.172	0.001	0.009	0.408	1.39E-05	5.34E-04	0.46
DF19	0.054	0.042	0.010	1.11E-04	0.003	1.023	0.001	0.022	0.383	1.30E-05	7.85E-04	0.47
DF20	0.087	0.038	0.011	1.69E-04	0.003	0.917	0.009	0.025	0.354	1.20E-05	7.26E-04	0.46
DF21	0.050	0.042	0.013	9.80E-04	0.005	1.381	0.003	0.028	0.370	1.26E-05	8.03E-04	0.48
DF22	0.080	0.035	0.009	6.82E-04	0.005	1.162	0.006	0.039	0.358	1.22E-05	6.63E-04	0.47

(Klavins and Potapovics 2008; Rakib et al. 2021). Pb found in substantial concentrations in the studied dried fish owes its origin from ground superficial erosion, atmospheric deposition, and anthropogenic activities. Pb formation in marine waters is strongly influenced by carbonates, chlorides, and organic natural ligands (Rodriguez-Hernandez et al. 2015; Vizuete et al 2019). The one-sample *t*-test revealed that all heavy metals, except Cr, exceeded the recommended limit, including Zn, Co, Fe, Cu, Ni, Pb, and Cd.

Conclusion

The level of radioactivity and heavy metal concentration in commonly consumed dried fish was investigated in the current study. The concentration of heavy metals and internal radiation dose through consumption of dried fish in the markets of Chennai city is minimal and within the acceptable limits only for few dried fish species. In conclusion, the findings of this study reveal that there is cancer associated risk for the studied

Table 6 Pearson correlation coefficient matrix for metal–metal in the analyzed dried fish samples

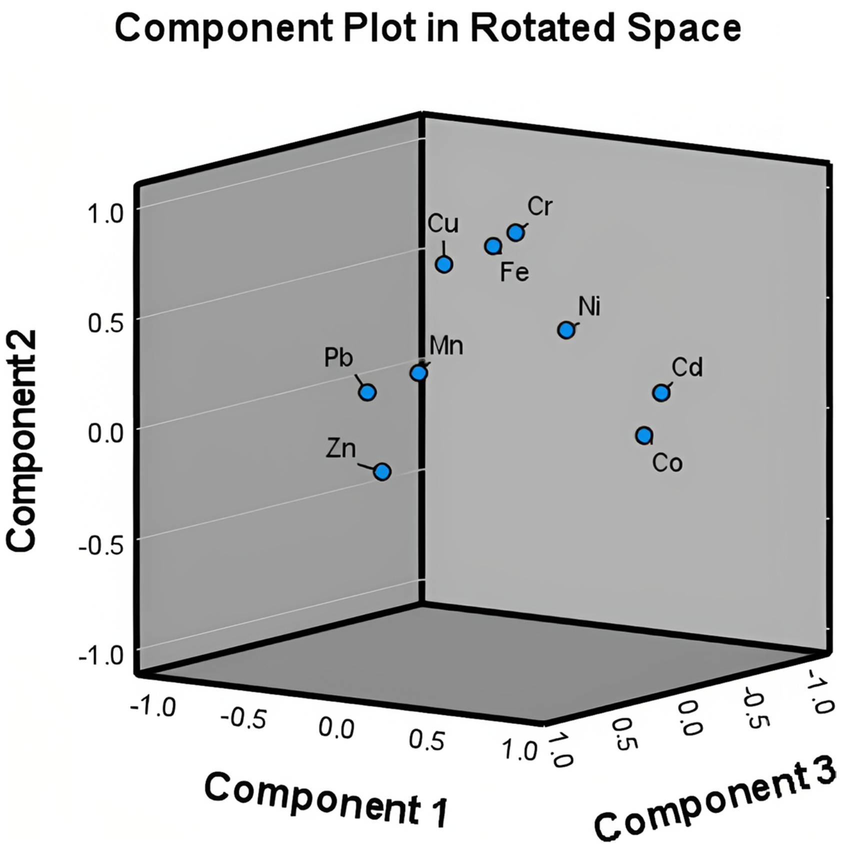
Metal	Zn	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb
Zn	1								
Cd	0.005	1							
Co	0.201	**.826****	1						
Cr	−0.071	0.263	0.205	1					
Cu	0.405	0.196	0.204	**.711****	1				
Fe	−0.054	0.224	0.081	.445*	.496*	1			
Mn	0.369	0.074	0.165	0.268	0.371	0.262	1		
Ni	0.191	**.545****	**.597****	**.609****	**.555****	0.305	.487*	1	
Pb	−0.251	**−.547****	**−.780****	−0.184	−0.190	−0.028	−0.347	**−.725****	1

**Correlation is significant at the 0.01 level (2-tailed)

*Correlation is significant at the 0.05 level (2-tailed)

The bold numbers were strongly significance

Fig. 2 Principal component analysis of Heavy metal analysis in dried fish



dried fish sample, due to the contamination of heavy metals Cd and Pb, especially, which shall pose health risk to consumers. The present study will serve as a database for assessing the risk of dried fish to human health through radiological and heavy metal aspects in other parts of the world.

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Author contribution M. Priyadharshini: conception and design, conducted experiment, writing of the original draft; M. Suhail Ahmed: methodology, manuscript preparation—writing, review editing, statistical interpretation of data; K. Pradhoshini: manuscript preparation—writing original draft, data curation; B. Santhanabharathi: manuscript preparation: review and editing; M. Shakeel Ahmed: methodology and data curation; Ismail Md Mofizur Rahman, Van-Hao Duong, and Lubna Alam: final drafting and reviewing the manuscript; Mohamed Saiyad Musthafa: supervision and final validation of the manuscript.

Data availability The data that supports the findings of this study are available on request from the corresponding author.

Declarations

Ethical approval Not applicable.

Consent to participate All authors contributed to the study conception and design. All authors read and approved the final manuscript.

Consent for publication All authors gave their consent for research publication.

Competing interests The authors declare no competing interests.

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