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RESEARCH ARTICLE

Heavy Metals in Commercial Marine Fish: Assumption and Accumulation as a Human Health Concern

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ABSTRACT

The study aimed to assess heavy metal pollution in marine fish species and predict potential health hazards to humans using computational toxicity analysis. The fish species *Otolithes cuvieri, Mugil cephalus, Leiognathus bindus,* and *Siganus canaliculatus* were analyzed for heavy metals using a flame atomic absorption spectrophotometer (FAAS). The highest concentrations of zinc, lead, and nickel were found in Ennore and Mandapam. The study revealed that the accumulation of heavy elements in the fish was in the order of Zn>Ni>Pb>Cu. No significant differences were found between the two sites, and the detected levels remained within permitted thresholds. Statistical data was used to create a computational program to determine individual toxicity levels using a partial least squares regression model. The study concluded that the fish species found at Ennore and Mandapam are suitable for human consumption, but proper waste management and safe disposal practices are crucial for heavy metals.

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Introduction

Ecological systems inherently include varied quantities of heavy metals, which exert a substantial influence on the environment. Improper waste disposal practices resulting from population increase and industrialization are significant contributors to water contamination (Vinodhini & Narayanan, 2008). The implementation of agricultural practices also played a role in the heightened pollution levels, resulting in adverse effects on both aquatic organisms and human well-being (Farombi et al., 2007). Consequently, both developing and developed nations express concern regarding significant meat pollution in aquatic ecosystems (Sweetly et al., 2021). In India, rivers and lakes have been inundated with sewage, industrial effluents, home and agricultural waste that contain heavy metals, poisonous compounds, and dangerous chemicals (Arumugam et al., 2021). This has caused significant damage to fish populations and other aquatic species (Nayak et al., 2010).

Exceeding the permissible limits of heavy metal consumption can have deleterious effects on the human body, known as biotoxicity (Al-Kahtany et al., 2023). Arsenic (As), Cadmium (Cd), Copper (Cu), Chromium (Cr), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni), and Zinc (Zn) are highly toxic substances that can be easily accumulated and integrated into the food chain of aquatic systems (Sakthivel et al., 2023). Fish, being proficient bioaccumulators, assimilate heavy metals in aquatic environments. Osmosis can take place through the process of intake, ion exchange across the gills, and adsorption by fish tissues (Salam et al., 2021).

Fish have varying bioaccumulation characteristics, with accumulation taking place in various parts of their bodies such as bones, liver, kidney, stomach, heart, muscle, operculum, vertebrae, and mussels (Arumugam & Ramaiah, 2018; Mohan et al., 2018). It distinguishes itself from other fish species based on variations in the solubility of metals in water, habitats and the availability of metals to organisms, feeding behavior, life cycles, physiological characteristics, and ecological interactions (Anandkumar et al., 2018; Perugini et al., 2014). A pollutant is defined as any material present in the environment that has undesirable consequences, resulting in the degradation of the environment, a decline in the overall quality of life, and perhaps leading to mortality.

Predictive toxicology is the scientific investigation of how observed harmful effects in humans or model systems can be utilized to anticipate the development of diseases, evaluate the associated risks, and implement preventive measures in humans. Cavill et al., (2009) utilized a Genetic Algorithm technique and selected specific samples and spectrum regions from the Consortium for Metabonomic Toxicology (COMET) database. They successfully developed reliable and predictive classifiers for liver and kidney toxicity. Therefore, the Consortium for Metabonomic toxicity has utilized this predictive technique by creating a comprehensive chronological database of marine fish treated with model toxins, specifically focusing on the analysis of AAS.

Material and Methods

Marine fish samples of *Otolithes cuvieri, Mugil cephalus, Leiognathus bindus,* and *Siganus canaliculatus* were collected at Ennore fish landing centre (13°15’N; 80°19’E) and Mandapam (South) fish landing centre (9°16′N; 79°7′E) between December 2009 and January 2010. The samples had the following measurements of length and weight: *Otolithes cuvieri* (17.5-21.5±2.00cm; 180±5g), *Mugil cephalus* (20.5-26.9±2.00cm; 175-182±5g), *Leiognathus bindus* (10.0-15.5±2.00cm; 90-160±5g), and *Siganus canaliculatus* (15.5-21.8±2.00cm; 165-190±5g).

Dry fish samples 10g were kept in the acid cleaned digested flask and 20ml of H2SO4: HNO3: HCLO4 at a ratio of 1:5:2 by volume were added. The mixture was subjected to heat using a hot plate at a temperature of 120°C until the tissue emitted vapors. The tube was extracted from the hot plate and left to cool. A volume of 5ml of hydrochloric acid (HCl) with a concentration of 2N was cautiously added to both the test solution and the standard. The mixture solution was given a few minutes to fully digest in order to decrease the volume by at least 1 ml. The digested suspension underwent filtration and was then diluted to a volume of 10ml using double distilled water. The samples are transported to sterile polypropylene containers for subsequent analysis. The concentrations of Zinc (Zn), copper (Cu), nickel (Ni), and lead (Pb) were measured using a flame atomic absorption spectrophotometer (Perkin Elmer AS 3100).

For the prediction of toxicity in people, seven factors are taken into account: name, age, sex, weight, fish consumption, fish variety, and fish purchase location (Table 1 and 2). The toxicity factors were computed and organized in the background, serving as input for statistical analysis.

Table 1. Average serving size of sea food among Indians

Age group	Male subjects	Female subjects
1-5	66	66
6-11	95	95
12-17	131	100
18-54	158	125
55-75	131	100
Over 75	95	95

** Quantity is in grams.

Result and Discussion

An analysis was conducted on the heavy metals, including Zn, Cu, Ni, and Pb, extracted from the entire fish specimen (Fig. 1 and Table 3). The species *O. cuvieri, M. cephalus, L. bindus,* and *S. canaliculatus* had the highest concentrations of Zn at the Ennore fish landing centre, with values of 0.928 ppm, 1.186 ppm, 1.145 ppm, and 0.93 ppm, respectively. Similarly, at the Mandapam fish landing centre, the species *O. cuvieri, M. cephalus, L. bindus,* and *S. canaliculatus* had concentrations of 0.907 ppm, 0.885 ppm, 0.925 ppm, and 0.808 ppm, respectively.

Table 2. Frequency of consumption among various groups (children below 11 are not considered) –oral survey data.

Frequency of fish food consumption	Women aged 15 - 44	Men aged 15 - 44	Women aged 45 and older	Men aged 45 and older
0	14	11	11	9
1 or more	86	89	89	91
2 or more	78	81	80	83
4 or more	56	58	61	63
8 or more	25	29	30	31
12 or more	12	14	15	14
24 or more	3	3	2	3
30 or more	2	1	2	2

Table 3. Heavy metal concentration (ppm) of various fish samples from Ennore and Mandapam

Fish landing centre/Fish Sample	Ennore				Mandapam			
	Zn	Cu	Ni	Pb	Zn	Cu	Ni	Pb
O. cuvieri	0.928	0.883	1.10	1.05	0.907	0.42	0.53	0.65
M. cephalus	1.186	0.203	0.93	0.92	0.885	0.37	0.48	0.69
L. bindus	1.145	0.012	1.53	0.94	0.925	0.38	0.63	0.67
S. canaliculatus	0.93	0.549	0.98	1.13	0.808	0.37	0.49	0.65

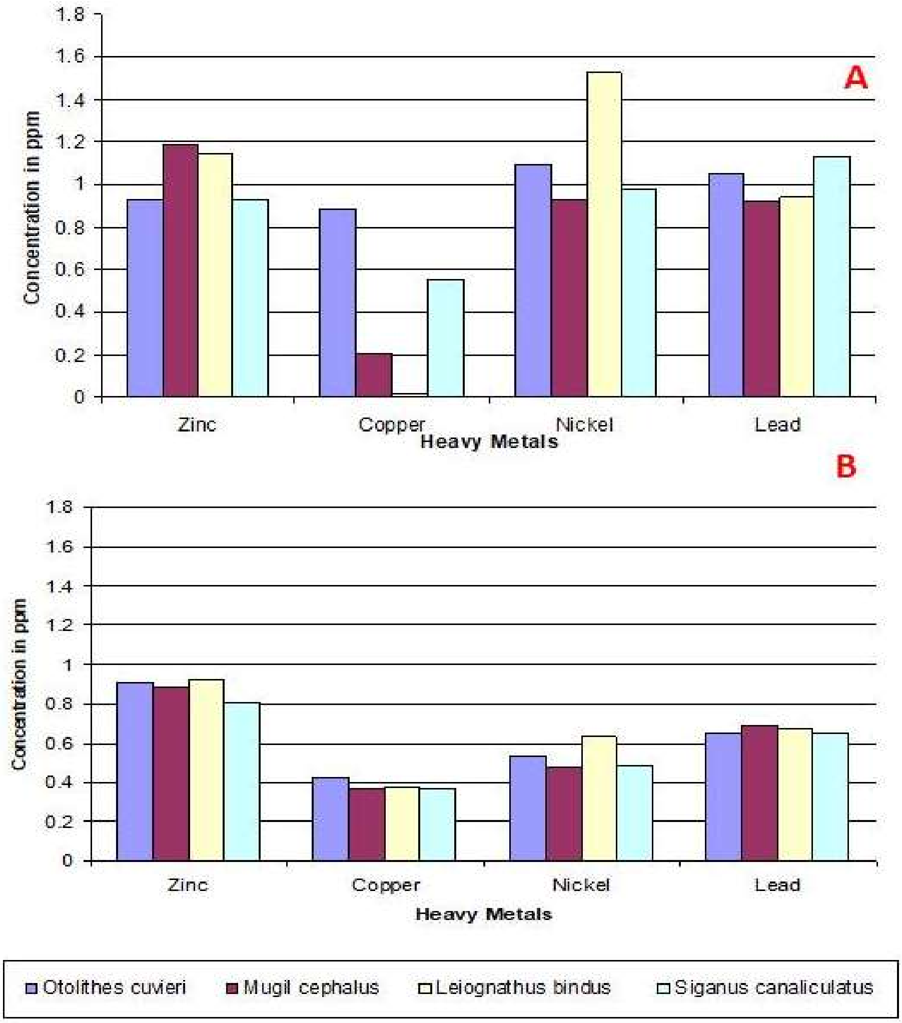

Fig 1. Accumulation of heavy metals in selected marine fishes from Ennore (A) and Mandapam (B) fish landing centre.

Table 4. Maximum permitted concentration of metals in marine biota muscle from various countries and organizations (mg kg-1 dry weight).

S. No.	Contaminant	U.K (Parsons, 1998 and 1999)	Australia (Otway, 1992)	Hong Kong (Parsons, 1998 and 1999)	European Regulation 466/2001/ EC	Indonesia *	#IRPTC (Tyrrell et al., 2005)
1.	Cadmium	-	0,80	8	0,4	-	-
2.	Lead	-	6,0	24	1,6	8	-
3.	Chromium	-	-	4	-	-	-
4.	Copper	80	-	-	-	80	-
5.	Zinc	200	-	-	-	400	-
6.	Arsenic	-	-	-	-	4	-
7.	Nickel	-	-	-	-	-	2

Noted: * Decree of General Director of Food and Drug Supervision No. 03725/B/SK/VII/89 concerning maximum limit of metals in food.
International Register of Potentially Toxic Chemicals, Geneva.

The highest concentration of copper (Cu) was detected at Ennore and Mandapam, with levels of 0.883 and 0.42 ppm (*O. cuvieri*), 0.203 and 0.37 ppm (*M. cephalus*), 0.0109 and 0.38 ppm (*L. bindus*), and 0.549 and 0.37 ppm (*S. canaliculatus*) respectively. The highest concentration of Nickel (Ni) was detected in *O. cuvieri* at Ennore and Mandapam, measuring 1.10 and 0.53 parts per million (ppm) respectively. *S. canaliculatus* in Ennore and Mandapam exhibited Ni concentrations of 0.98 ppm and 0.49 ppm, respectively. The highest concentration of lead (Pb) was found in *O. cuvieri* (1.05 ppm) and *S. canaliculatus* (1.13 ppm) collected from Ennore. On the other hand, the lowest concentration of nickel (Ni) was seen in *L. bindus* (0.67 ppm) and *S. canaliculatus* (0.65 ppm) collected from Mandapam. The Ni and Pb levels in the fish samples from both the Ennore and Gulf of Mannar regions are in close proximity to the European regulation and IRPTC standards. This suggests the need for vigilant monitoring of heavy metal contamination in marine biota.

Currently, the Government of India has not established a standardized protocol for assessing heavy metal pollution in marine biota. The permissible international limits of heavy metals in marine organisms are presented in Table 4. Prior research on fish tissue has primarily concentrated on the bioaccumulation of heavy metal pollutants (Bayen et al., 2005). Organ specific bio-accumulation studies also executed in gills, kidney, brine, heart, mussel and livers of fish as well as whole fish (Burger et al., 2005).

Organs and other tissues can contain heavy metal concentrations that are 200 – 400% higher compared to muscle tissue (Dione et al., 2023; Giarikos et al., 2023). Thus, the outcomes obtained for heavy metal detection were recorded for the entire body. In contrast Chen et al., (2023) noticed that the levels of Cd, Cu, and Zn in the entire body of fish were relatively greater compared to the muscle tissue of mullet, drum, and sea catfish (Chen et al., 2023). The presence of high concentrations of heavy metals in water is known to pose a significant risk to aquatic creatures, as highlighted (Jefferson et al., 2023; Tran-Lam et al., 2023). Consequently, the examination of heavy metal content in fish guarantees the safety of their diet (Curtin & McCullough, 2023; Liu et al., 2021; Silva et al., 2023).

The Toxicity Predictor is designed with a specific focus on utilizing toxicogenomics to address environmental health concerns. This procedure was crucial for evaluating the vulnerability to heavy metals, necessitating more comprehensive data or information to forecast the concentration of heavy metals in the food web. Figure 2 displayed the user interface for predicting toxicity based on the sample. The current strategy being utilized by computational tools is the creation of comprehensive, unified models based on physiology to study the movement and effects of toxins (Abdel-Rahman & Kauffman, 2004; Danhof et al., 2007). Therefore, there is a significant disparity in the values of the theoretically bioavailable metal percentage predicted by various modeling programs/models. These values are crucial for comprehending and establishing a connection between the intake of metals and their levels in aquatic organisms.

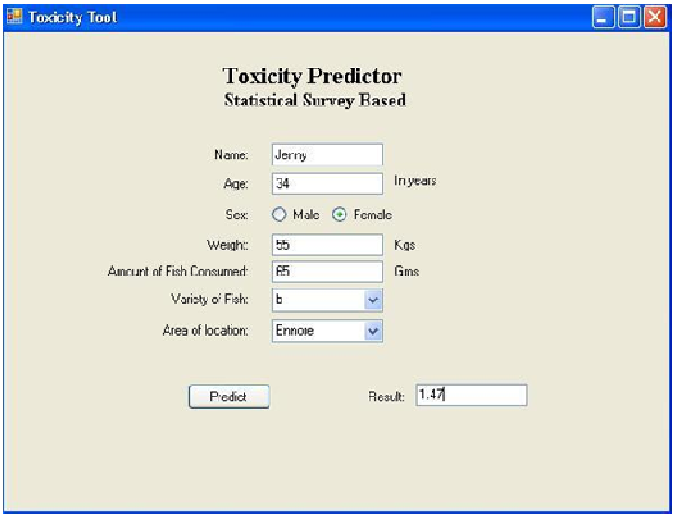

Fig 2. The snap shot of the user interface of the toxicity predictor for the sample data.

Conclusion

As a result of the actions of industrial and domestic sources, the water system has experienced an increased influx of heavy metal contaminants, leading to elevated levels of heavy metal deposition in aquatic creatures. The sequence of heavy metal accumulation was as follows: zinc (Zn) had the highest concentration, followed by nickel (Ni), lead (Pb), and copper (Cu). For the Ennore and Mandapam fish landing centers, the order of accumulation was Ni>Zn>Pb>Cu. A bioinformatics toxicity prediction model was created to safeguard the safety of seafood intake by mitigating the detrimental impact of heavy metals on fish and human health. Monitoring the biology of fish and water is necessary to guarantee the safety of seafood. Hence, it is imperative to adhere to appropriate methods of disposing industrial effluent and domestic sewage.

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Conflict of interest

All authors declare that there is no conflict of interest in this work.

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