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Health Risk Assessment of Heavy Metal Residues in Some Retailed Fish from Dakahlia Governorate, Egypt

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Abstract

IN EGYPT, various fish species are commonly consumed for their rich nutritional value, widespread availability, and appealing taste. However, chemical residues, particularly heavy metals, can accumulate in fish muscles and internal organs, posing significant health risks to consumers. In this study, 80 samples of tilapia, mackerel, catfish, and mullet were obtained from different fish markets in Dakahlia province, Egypt, to analyze heavy metal residues, specifically lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), and copper (Cu), using an atomic absorption spectrophotometer. Additionally, the detected metals were assessed by calculating the estimated daily intake (EDI), hazard quotient (HQ), and hazard index (HI). Results revealed that Cd, Pb, Hg, As, and Cu were detected in 91.3%, 100%, 78.8%, 100%, and 100% of the examined fish, respectively. The mean concentrations (mg/kg) in tilapia, mackerel, catfish, and mullet were as follows: for Cd, 0.03±0.004, 0.04±0.01, 0.05±0.004, and 0.06±0.01; for Pb, 2.39±0.21, 1.53±0.22, 1.64±0.17, and 1.33±0.23; for Hg, 0.08±0.01, 0.20±0.03, 0.12±0.04, and 0.17±0.03; for As, 8.43±0.48, 12.90±0.60, 12.26±0.35, and 6.85±0.38; and for Cu, 3.29±0.25, 4.16±0.36, 0.77±0.05, and 3.41±0.26. All fish samples were within acceptable limits for Cu residues but were entirely unacceptable for As residues. The acceptability for Cd, Pb, and Hg varied across the samples. Health risk assessment showed hazard indices of 20.11, 30.34, 29, and 16.18 for tilapia, mackerel, catfish, and mullet, respectively, all exceeding the threshold value of 1, indicating significant health risks. Consequently, consumption of these fish species poses potential health hazards due to the high cumulative risk associated with heavy metals contamination.

Keywords: Fish, Heavy metals, Health Risk, Toxic Residues.

Introduction

Fish serve as a vital source of premium animal protein, essential minerals, vitamins, and lipids, contributing significantly to human nutrition. In Egypt, a variety of fish species are widely consumed due to their palatability, nutritional value, and availability [1]. The most commonly consumed species include Nile tilapia (*Oreochromis niloticus*), mullet (*Mugil cephalus*), mackerel (*Scomber scombrus*), and catfish (*Clarias lazera*) [2,3].

Nile tilapia, a staple in Egyptian diets, is primarily sourced from the Nile River and is favoured for its rich nutritional profile and affordability. Mullet, a popular choice in traditional Egyptian cuisine, is highly valued for its high protein content and a balanced composition of saturated and unsaturated fatty acids [4]. Mackerel, an imported frozen fish species, is also an excellent source of proteins, omega-3 fatty acids, and crucial micronutrients that are vital for human being health [5]. Additionally, catfish is an important species for aquaculture due to its resilience to adverse environmental conditions and its ability to produce meat with significant nutritional benefits [6].

Despite these nutritional benefits, fish are susceptible to contamination with toxic heavy metals, which can enter aquatic environments from various sources and accumulate in fish muscles and organs [7]. Heavy metals pollution in aquaculture primarily originates from the use of pesticides, fertilizers, and industrial waste [8]. The accumulation of toxic

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metals in fish is influenced by factors including sex, age, species, size, and organ activity [9,10].

Consuming of fish contaminated with heavy metals results in the bioaccumulation of such toxic substances in the body, causing severe health issues, including neuromuscular disorders, mental retardation, malformations, liver and kidney damage, and various cancers [11]. Cadmium (Cd) is a highly toxic metal that damages multiple organs, including the liver, where it elevates liver enzyme levels [12]. It also induces nephrotoxicity by damaging kidney tubules [13]. Additionally, cadmium compounds such as sulphate, chloride, and oxide are recognized carcinogens [14]. Lead (Pb) also exerts hepatotoxic effects, increasing liver function test values and causing significant liver damage [15]. Mercury (Hg), found in both inorganic forms (e.g., mercuric chloride) and organic forms (e.g., methyl and ethyl mercury), poses severe health risks, with toxic effects that vary depending on its form [16].

Arsenic (As) is another harmful heavy metal that disrupts vital enzymes, such as sulfhydryl group-containing enzymes and pyruvate dehydrogenase, leading to cellular damage. It also causes capillary endothelium damage, increases vascular permeability, and may result in circulatory collapse [17]. Copper (Cu), although an essential trace element with antioxidant properties, becomes toxic in high doses, particularly to the liver, where it causes hepatocellular degeneration and necrosis [18]. The present study aimed to detect the residues of cadmium (Cd), lead (Pb), mercury (Hg), arsenic (As), and copper (Cu) in tilapia, mackerel, catfish, and mullet. Additionally, it aimed to evaluate the daily intake of these metals and assess the hazard index associated with their consumption.

Material and Methods

Samples collection and preparation

A total of eighty samples of tilapia (*Oreochromis niloticus*), mullet (*Mugil cephalus*), mackerel (*Scomber scombrus*), and catfish (*Clarias lazera*) (20 from each sample) were collected from various fish markets in Dakahlia governorate, Egypt. The samples were stored in the refrigerator till metal extraction and measurements completed at the Central Laboratory of the Faculty of Veterinary Medicine, Zagazig University, Egypt.

Analytical procedures

From each fish, 1 gram of muscle was taken and digested using 5 ml of acid mixture (3 ml nitric acid 65% and 2 ml perchloric acid 70%). Then, it was then left at room temperature for twelve hours before being incubated at 70°C for three hours with regular stirring. After digestion, the samples were diluted by addition of 20 ml double distilled water then filtered by filter papers. The filtrated tubes were kept at room temperature, till measurement of heavy metals as reported by Darwish *et al*. [19].

Estimation of toxic heavy metals.

Atomic absorption spectrophotometer (AAS), AA240 FS (VARIAN, Australia) was used to measure Cd, Pb, Hg, As, and Cu using the graphite furnace atomic absorption spectroscopy, meanwhile, Hg was measured by the hydride vapour atomic absorption spectroscopy [14]. Absorbency of Cd, Pb, Hg, and Cu was recorded and the concentrations were calculated according to the following equation:

$$C=R \text{ x } (D/W)$$

Where, C is the metal concentration (wet weight); R is the digital scale of AAS Reading; D is the sample dilution and W is the sample weight.

Quality assurance and quality control

The analytical procedures were validated using the Fish Protein Reference Material (DORM-3) provided by the National Research Council of Canada. The recovery rates for Cd, Pb, Hg, As and Cu were 98%, 97%, 95%, 98%, and 98%, respectively. The detection limits were 0.005 µg/g for Cd, 0.01 µg/g for Pb, and 0.02 µg/g for Hg, As, and Cu [19].

Estimated daily intake (EDI)

The following equation was used to calculate the estimated daily intake for the detected metals according to US EPA [20].

$$\text{EDI } (\mu g/kg/day) = \frac{Cm \text{ x } FIR}{BW}$$

FIR is the fish intake rate by the Egyptians (48.57 g/day) according to FAO [21], Cm is the concentration of the detected metal, and BW is the body weight of the adult Egyptians (70 kg).

Assessment of health risks

Health risk effects of the measured heavy metals were quantified using the hazard quotient (HQ) based on the following equation US EPA [22].

$$HQ = EDI/RFD*10^{-3}$$

RFD (mg/kg/day) is the reference dose for cadmium, lead, mercury, arsenic, and copper (0.001, 0.004, 0.0005, 0.0003, and 0.04, respectively) according to US EPA [22].

The hazard index (HI) was computed to evaluate the non-carcinogenic effects of mixed metals according to Hussein et al. [23] based on the following equation:

$$HI = \sum HQi$$

i is the HQ for each metal. If the HQ and HI values are more than 1, there are possible risks on health [24].

Statistical analysis

Tukey–Kramer honestly significant difference test was used to compare the samples by one-way

ANOVA (SAS Institute, Cary, NC). Statistical significance was considered at $p < 0.05$. The data were presented as means ± standard error (S.E.).

Results

Results in Table 1 showed that Pb, As, and Cu were detected in all examined fish species (100%), meanwhile, Cd and Hg were detected in 91.3% and 78.8% of the examined fish samples. The prevalence of Cd was 80%, 85%, 100%, and 100%, while, Hg was 100%, 80%, 35%, 100%, and 78.8% in tilapia, mackerel, catfish, and mullet, respectively (Table 1).

The concentration (Mean±S.E.) of Cd was 0.03±0.004, 0.04±0.01, 0.05±0.004, and 0.06±0.01 (mg/kg) in tilapia, mackerel, catfish, and mullet, respectively. Cd concentration was significantly ($p <$ 0.05) higher in mullet than catfish, mackerel, and tilapia (Table 2). The percentages of the accepted samples of tilapia, mackerel, catfish, and mullet were 100%, 40%, 65%, and 25%, respectively, based on their content of Cd (Table 3).

In addition, the average Pb concentration was notably higher ($p < 0.05$) in tilapia (2.39±0.21 mg/kg) compared to mackerel (1.53±0.22 mg/kg), catfish (1.64±0.17 mg/kg), and mullet (1.33±0.23 mg/kg) as illustrated in Table 2. The recorded data illustrated that all examined samples of tilapia, mackerel, and catfish were unaccepted for Pb, meanwhile, 45% of mullet samples were accepted (Table 3).

Concerning to Hg, its concentration (Mean±S.E.) in tilapia, mackerel, catfish, and mullet was 0.08±0.01, 0.20±0.03, 0.12±0.04, and 0.17±0.03 mg/kg, respectively (Table 2). There were significant differences between the examined samples ($p < 0.05$) based on their content of Hg. All samples of tilapia were 100% accepted for Hg, while, 40%, 65%, and 75% of the examined mackerel, catfish, and mullet were accepted (Table 3).

As recorded in Table 2, the average concentration of As (mg/kg) was significantly higher ($p < 0.05$) in mackerel (12.90±0.60) and catfish (12.26±0.35) than tilapia (8.43±0.48) and mullet (6.85±0.38). All of the examined fish species were unaccepted for As level (Table 3).

The present study documented that Cu concentration (Mean±S.E.) was 3.29±0.25, 4.16±0.36, 0.77±0.05, and 3.41±0.26 mg/kg in tilapia, mackerel, catfish, and mullet samples, respectively. A significant difference ($p < 0.05$) was detected between the examined fish species (Table 2). All of the examined fish samples were accepted for Cu concentration as illustrated in Table 3.

Spearman's correlation was computed, as presented in Table 4, to investigate the tendency of metals to accumulate in fish. Interestingly, the results highlighted interspecies variations in the tendency of metal accumulation. For instances, significant positive correlations were detected between Cd-Hg (r = 0.877, p = 0.00) in catfish samples, Cd-As (r = 0.632, p = 0.003) in mullet samples, Cd-Cu (r = 0.538, p = 0.014) in catfish samples, Pb- As (r = 0.538, p = 0.014) in catfish samples, Hg-As (r = 0.877, p = 0.000) in catfish samples, As-Cu (r = 0.538, p = 0.014) in catfish samples; Pb-As (r = 0.600, p = 0.005) in tilapia; Pb-As (r = 0.700, p = 0.001) in mackerel samples, Hg-Cu (r = 0.900, p = 0.000) in mackerel samples, Hg-Cu (r = 0.949, p = 0.000) in mullet samples (Tables 4). However, significant negative correlations were detected between Cd-Pb (r = -0.538, p = 0.014) in catfish samples; Cd-Pb (r = -0.949, p = 0.000) in mullet samples, Pb-As (r = -0.800, p = 0.00) in mullet samples (Tables 4).

The EDI of the detected metals was illustrated in Table 5. From tilapia, mackerel, catfish and mullet, it was 0.02, 0.03, 0.04, and 0.04 μg/ kg/ day, respectively for Cd; 1.66, 1.06, 1.14, and 0.92 μg/kg/ day, respectively for Pb; 0.05, 0.14, 0.08, and 0.11 μg/kg/day, respectively for Hg; 5.85, 8.95, 8.51, and 4.75 μg/kg/day, respectively for As; and 2.28, 2.89, 0.53, and 2.37 μg/kg/day, respectively for Cu.

The recent study documented that the HQ due to Cd, Pb, Hg, As, and Cu was 0.02, 0.42, 0.11, 19.5, and 0.06, respectively for tilapia; 0.03, 0.27, 0.14, 29.83, and 0.07, respectively for mackerel; 0.06, 0.29, 0.28, 28.36, and 0.01, respectively for catfish; and 0.04, 0.23, 0.02, 15.83, and 0.06, respectively for Cu (Table 6). The calculated HI due to the detected metals in tilapia, mackerel, catfish, and mullet was 20.11, 30.34, 29, and 16.18, respectively (Table 6).

Discussion

In this study, frozen marketed turkey breast and The recent study assessed the level of heavy metals contamination and its impact on public health in different species of fish consumed in Egypt. The examined fish species were contaminated by different types of heavy metals at varying degrees; Pb, As, and Cd detected in all samples. Moreover, Hg had the lowest prevalence in the examined fish. Generally, Cd concentration varied across the examined samples; with mullet and catfish showing the highest levels (100%), followed by mackerel (85%), while, tilapia had the lowest Cd concentration (80%). Similar results were reported by Hassan *et al*. [14] for catfish, Djedjibegovic *et al*. [25] for mackerel, and Hussein *et al*. [7] for tilapia and mullet. Meanwhile, higher results were reported by Ali *et al*. [6] for tilapia and mullet (0.05 mg/kg), Hemmatinezhad *et al*. [26] for tilapia (1.7 mg/kg), and Hasanein *et al*. [27] for catfish and tilapia (1.14±0.18 and 1±0.24 mg/kg). As stated by EOS [28], the residual limit of Cd in fish muscles should not exceed 0.05 mg/kg, therefore all the examined tilapia samples were accepted. The industrial and agricultural activities are principal sources of environmental contamination by Cd [25].

Concentration of Pb varied between the examined fish samples; tilapia species was the highest in Pb residues followed by catfish, mackerel and mullet samples. In line with this study, Hasanein *et al*. [27] reported nearly similar results for catfish and tilapia. However, lower concentrations were recorded by Elnabris *et al*. [29] for tilapia (0.12 mg/kg), Damodharan and Reddy [30] for tilapia (0.02 mg/kg), Shokr *et al*. [31] for catfish and tilapia (0.64 ± 0.01 and 0.49 ± 0.01 mg/kg), and Djedjibegovic *et al*. [25] for mackerel (0.007±0.005 mg/kg). Higher results were recorded by Abdel-Baki *et al*. [32] for tilapia (39.7±2.3 mg/kg) and Ali *et al*. [6] for mullet (0.3 mg/kg). According to the EOS [28], which sets the maximum permissible limit for lead (Pb) residues in fish at 0.1 mg/kg, all of the examined fish species were unaccepted for Pb residues except mullet samples, which were accepted (45%). Exposure of fish to Pb in high doses causes damages in the blood and nerve cell [33], furthermore, Pb results in nephrotoxicity, hepatotoxicity, and neurotoxicity in humans [34].

Regarding Hg concentration in fish samples under examination, mackerel samples had the highest concentration compared to other species, followed by mullet, catfish and tilapia. Nearly similar concentrations were reported by Djedjibegovic *et al.* [25] for mackerel. This can be explained by the fact that mackerel, being a predatory marine fish, accumulates higher levels of mercury (Hg) through biomagnification as it consumes smaller fish. In contrast, mullet and catfish, which are bottom feeders or omnivores, and tilapia, which is primarily herbivorous, had lower Hg levels. Habitat differences also play a role, as marine environments typically have higher Hg contamination than freshwater systems. Additionally, species-specific metabolism influences Hg uptake and retention. These findings align with Djedjibegovic *et al.* [25], confirming that predatory marine fish accumulate more mercury than lower-trophic species.

Other studies reported higher results were recorded by Abdel-Baki *et al*. [32] for tilapia (3.1± 1.9 mg/kg), Shokr *et al*. [31] for catfish and tilapia (1.10 ± 0.02 and 0.89 ± 0.01 mg/kg), Hasanein *et al*. [27] for catfish and tilapia (0.46±0.13 and 0.54±0.13 mg/kg). According to EOS [28], the permissible Hg limit in fish muscles is 0.02 mg/kg), so all examined tilapia samples tested were acceptable. One of the most widespread contaminants in fish is mercury; it can cause many adverse health effects, including neurotoxicity as well as bioaccumulation in different tissues and organs [35].

Generally, mackerel and catfish samples had the highest concentration of As residues, while mullet samples had the lowest concentration. This can be attributed to the fact that mackerel and catfish accumulate higher arsenic concentrations due to their dietary habits, environmental exposure, and bioaccumulation mechanisms. In contrast, mullet, which feeds lower on the food chain in coastal waters, has the lowest arsenic levels because it is less exposed to arsenic-rich sediments and predatory accumulation pathways. Unlike this study, Ghuniem *et al*. [36], Sallam *et al*. [37], and Hasan *et al*. [38] reported lower results in fish samples under examination. In Egypt, there is no legislated regulations on the permissible limits of arsenic residues in fish but according to the Institute of Standards and Industrial Research of Iran (ISIRI) [39] limit for As (0.2 mg/kg), all of the examined samples were 100% unaccepted for As. Arsenic toxicity is related to the inorganic form which is highly toxic, resulting in different types of cancer, cardiovascular disorders, developmental retardation and death in children [40].

Copper is a vital trace element that is naturally present in living organisms, but in high concentrations, it can cause toxicity [41]. In our study, mackerel samples had the highest concentration of Cu followed by mullet and tilapia; meanwhile, catfish had the lowest Cu concentration. Nearly similar result of Cu was reported by Mortuza and Al-Misned [42] and Hassan *et al*. [14]. Lower concentrations were reported by Ali *et al*. [6] in tilapia and mullet (2.497 and 0.229 mg/kg) and Al-Weher [43] reported 2.9 ± 0.3 mg/kg in tilapia. Meanwhile, Ali et al. [6] reported higher concentrations of Cu in catfish. Fish species under examination didn’t exceed the EOS [28] limit (not more than 15 mg/kg), so all samples were 100% accepted for Cu.

Spearman`s correlation investigate the inter-metal`s tendency for accumulation in fish by calculation of Spearman`s coefficient factors in the examined fish species. There were interspecies-dependent differences in the accumulation of the tested metals, which can be attributed to the physiological nature of different species of fish for detoxification of these metals. These results are consistent with other studies reported the inter-metal correlations [19,44].

Untreated industrial and agricultural discharges and improper uses of chemicals are the primary sources of heavy metal contamination to the aquatic environment [40]. The variation of detected metals in fish species under examination attributes to the species variation in tissue accumulation; in addition to differences in feeding, and ecological habits of fish species [35].

In the present study, most of the examined fish species exceeded the residual limits for the detected metals. Consequently, the estimated daily intake (EDI), hazard quotient (HQ), and hazard index (HI) were calculated to assess the potential health risks to consumers from these fish species. The computed HQ values for Cd, Pb, Hg, and Cu were below one, indicating minimal risk for these metals individually. However, the HQ for As was significantly higher than one, resulting in a high HI for the examined fish species. Among the species, mackerel exhibited the highest HI, followed by catfish, tilapia, and mullet. These findings suggest potential adverse health effects associated with the consumption of these fish due to the presence of toxic metals.

The results of this study align with the findings of Hussein et al. [24], who also reported HI values greater than one, indicating significant health risks. However, they contradict the findings of Rajan and Ishak [45] and Sheta et al. [46], who observed HI values below one, suggesting lower levels of risk.

Conclusion

The current study was conducted to detect the concentration heavy metals in some fish species (tilapia, mackerel, catfish and mullet) and to evaluate some hazardous indicators to these metals. From the obtained results cadmium, lead, mercury, arsenic and copper were in fish under examination at variable concentrations. Some of the examined species exceeded the maximum permissible levels of Cd, Pb, Hg, and Cu; while all the examined samples exceeded the maximum permissible levels of As. An expected health hazards was calculated after computing EDI, HQ, and HI because HI was higher than 1. Therefore, hygienic measures should be taken in consideration by the authorities.

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Declaration of Conflict of Interest

Authors declare that there is no conflict of interest.

TABLE 1. Incidence of samples contaminated by heavy metals (N=20 of each).

Samples	Tilapia	Mackerel	Catfish	Mullet	Total
Cd	16(80%)	17(85%)	20(100%)	20(100%)	73(91.3%)
Pb	20(100%)	20(100%)	20(100%)	20(100%)	80(100%)
Hg	20(100%)	16(80%)	7(35%)	20(100%)	63(78.8%)
As	20(100%)	20(100%)	20(100%)	20(100%)	80(100%)
Cu	20(100%)	20(100%)	20(100%)	20(100%)	80(100%)

N: Number of examined samples.
Cd: Cadmium; Pb: Lead; Hg: Mercury; As: Arsenic; and Cu: Copper.

TABLE 2. Statistical analytical results of some heavy metal residues (mg/kg) in the examined samples (N=20 of each).

Samples		Tilapia	Mackerel	Catfish	Mullet
Cd	**Min-Max**	0.01-0.04	0.02-0.07	0.03-0.07	0.01-0.1
	Mean±S.E.	$0.03^{a}\pm0.004$	$0.04^{b}\pm0.01$	$0.05a^{b}\pm0.004$	$0.06^{a}\pm0.01$
Pb	**Min-Max**	0.60-3.12	0.67-3.34	0.57-2.29	0.07-2.74
	Mean±S.E.	$2.39^{a}\pm0.21$	$1.53^{b}\pm0.22$	$1.64^{b}\pm0.17$	$1.33^{b}\pm0.23$
Hg	**Min-Max**	0.05-0.12	0.17-0.33	0.08-0.34	0.03-0.36
	Mean±S.E.	$0.08^{c}\pm0.01$	$0.20^{a}\pm0.03$	$0.12^{bc}\pm0.04$	$0.17^{ab}\pm0.03$
As	**Min-Max**	5.01-11.33	8.23-15.99	10.37-14	4.77-9.12
	Mean±S.E.	$8.43^{b}\pm0.48$	$12.90^{a}\pm0.60$	$12.26^{a}\pm0.35$	$6.85^{c}\pm0.38$
Cu	**Min-Max**	1.40-4.42	1.83-6.51	0.50-1.07	2.29-4.67
	Mean±S.E.	$3.29^{b}\pm0.25$	$4.16^{a}\pm0.36$	$0.77^{c}\pm0.05$	$3.41^{b}\pm0.26$

N: Number of examined samples.
Cd: Cadmium; Pb: Lead; Hg: Mercury; As: Arsenic; and Cu: Copper.
Min: Minimum; Max: Maximum; S.E: Standard Error
a-b-c: Means within the same row (Horizontally) carrying different superscripted letter are significantly different ($p < 0.05$).

TABLE 3. Accepted samples (N=20) according to their contents of heavy metals.

Fish species	MRL (mg/Kg)	Tilapia	Mackerel	Catfish	Mullet
Cd	0.05*	20(100%)	8(40%)	13(65%)	5(25%)
Pb	0.1*	0	0	0	9(45%)
Hg	0.2*	20(100%)	8(40%)	13(65%)	15(75%)
As	0.2**	0	0	0	0
Cu	15*	20(100%)	20(100%)	20(100%)	20(100%)

*MRL: Maximum Residual Limit stipulated by Egyptian Organization for Standardization "EOS" (2010) [28].
** MRL According to ISIRI (2014) [39] No. 6952(Fish and fish products -Canned tuna fish in brine-Specifications and test methods).

TABLE 4. Correlation analysis among the examined metals in the muscles of different fish species.

Detected metals		Tilapia		Mackerel		Catfish		Mullet	
		r	***p***	***r***	***p***	***r***	***p***	***r***	***p***
Cd	**Pb**	0.112	0.639	-0.051	0.830	**-0.538**	**0.014**	**-0.949**	**0.000**
Cd	**Hg**	0.057	0.810	-0.205	0.385	**0.877**	**0.00**	0.316	0.174
Cd	**As**	-0.447	0.048	0.410	0.072	1	-	**0.632**	**0.003**
Cd	**Cu**	-0.335	0.148	0.359	0.120	**0.538**	**0.014**	0.333	0.151
Pb	**Hg**	-0.205	0.385	0.300	0.199	-0.067	0.777	-0.200	0.398
Pb	**As**	**0.600**	**0.005**	**0.700**	**0.001**	**0.538**	**0.014**	**-0.800**	**0.000**
Pb	**Cu**	-0.200	0.398	-0.100	0.675	-1	-	-0.316	0.174
Hg	**As**	-0.410	0.072	0.200	0.398	**0.877**	**0.000**	-0.400	0.081
Hg	**Cu**	-0.205	0.385	**0.900**	**0.00**	0.067	0.777	**0.949**	**0.000**
As	**Cu**	-0.400	0.081	-0.400	0.081	**0.538**	**0.014**	-0.211	0.372

r: Spearman's correlation factor
p: Probability
Bold values show significant correlation between each two metals.

TABLE 5. Estimated daily intake (µg/kg/day) of the detected heavy metals.

Fish species	Tilapia	Mackerel	Catfish	Mullet
Cd	0.02	0.03	0.04	0.04
Pb	1.66	1.06	1.14	0.92
Hg	0.05	0.14	0.08	0.11
As	5.85	8.95	8.51	4.75
Cu	2.28	2.89	0.53	2.37

The estimated daily intake for the detected toxic metals was estimated based on this following equation

EDI= $\frac{Cm\ x\ FIR}{BW}$ (US EPA, 2010)

Where; (FIR) is the fish intake rate (48.57 g/day) by the Egyptians according to FAO (2010) [21]; (Cm) is the concentration of heavy metal; and (BW) is the adult Egyptian body weight (70 kg).

TABLE 6. Hazard quotient (HQ) and hazard index (HI) of the detected heavy metals.

Fish species	Tilapia	Mackerel	Catfish	Mullet
Cd	0.02	0.03	0.06	0.04
Pb	0.42	0.27	0.29	0.23
Hg	0.11	0.14	0.28	0.02
As	19.5	29.83	28.36	15.83
Cu	0.06	0.07	0.01	0.06
HI	20.11	30.34	29	16.18

Health risks were calculation of hazard quotient (HQ) based on the following equation:

HQ = $\frac{EDI}{RFD}$ x 10^{-3} (US EPA, 2010) [20].

Where; (RFD mg/kg/day) is the reference dose; its value for cadmium, lead, mercury, arsenic, and copper (0.001, 0.004, 0.0005, 0.0003, and 0.04, respectively) (US EPA, 2010) [20].

Furthermore, hazard index (HI) was calculated to assess non-carcinogenic effects of mixed metals.

$$HI = \sum HQi$$

Where; (i) is the HQ for each metal. When HQ and HI values are higher than 1, there are possible risks on human health, but there are no health risks when the value is less than 1.

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تقييم المخاطر الصحية لمتبقيات المعادن الثقيلة في بعض الأسماك المباعة بالتجزئة من محافظة الدقهلية، مصر

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الملخص

في مصر، تُستهلك أنواع مختلفة من الأسماك على نطاق واسع نظرًا لقيمتها الغذائية العالية وتوافرها الكبير ومذاقها المميز. ومع ذلك، يمكن أن تتراكم المتبقيات الكيميائية، لا سيما المعادن الثقيلة، في عضلات وأعضاء الأسماك الداخلية، مما يشكل مخاطر صحية كبيرة على المستهلكين. في هذه الدراسة، تم جمع 80 عينة من أسماك البلطي، والماكريل، والقراميط، والبوري من أسواق مختلفة للأسماك في محافظة الدقهلية، مصر، لتحليل متبقيات المعادن الثقيلة، تحديدًا الرصاص(Pb) ، والكادميوم(Cd) ، والزئبق(Hg) ، والزرنيخ(As) ، والنحاس(Cu) ، باستخدام مطياف الامتصاص الذري. بالإضافة إلى ذلك، تم تقييم المخاطر الصحية المرتبطة بهذه المعادن من خلال حساب المدخول اليومي المقدر(EDI) ، ومعدل الخطر(HQ)، ومؤشر الخطر(HI). أظهرت النتائج أن الكادميوم، والرصاص، والزئبق، والزرنيخ، والنحاس تم الكشف عنها في 91.3%، 100%، 78.8%، 100%، 100% من الأسماك التي تم فحصها، على التوالي. وكانت التركيزات في أسماك البلطي، والماكريل، والقراميط، والبوري بمتوسط قيم (ملغم/كغم) ، 0.004±0.03 ، 0.01±0.04، 0.004±0.05، 0.01±0.06 بالنسبة للكادميوم ؛ 2.39±0.21 ، 1.53±0.22، 1.64±0.17، 1.33±0.23 بالنسبة للرصاص ؛ 0.08±0.01 ، 0.20±0.03، 0.12±0.04، 0.17±0.03 بالنسبة للزئبق ؛ 8.43±0.48، 12.90±0.60، 12.26±0.35، 6.85±0.38 بالنسبة للزرنيخ ؛ 3.29±0.25، 4.16±0.36، 0.77±0.05، 3.41±0.26 بالنسبة للنحاس على التوالي. كانت جميع عينات الأسماك ضمن الحدود المقبولة لمتبقيات النحاس، لكنها كانت غير مقبولة تمامًا لمستويات الزرنيخ. أما بالنسبة للكادميوم والرصاص والزئبق، فقد اختلفت مستويات القبول بين العينات. أظهر تقييم المخاطر الصحية أن مؤشرات الخطر كانت 20.11 ، 30.34، 29، 16.18 لأسماك البلطي، والماكريل، والقراميط، والبوري على التوالي، وهي جميعها تتجاوز الحد المسموح به وهو الواحد الصحيح، مما يشير إلى وجود مخاطر صحية كبيرة. بناءً على ذلك، فإن استهلاك هذه الأنواع من الأسماك قد يشكل مخاطر صحية محتملة بسبب الارتفاع الكبير في المخاطر التراكمية الناتجة عن تلوثها بالمعادن الثقيلة.

الكلمات الدالة: الأسماك، المعادن الثقيلة، المخاطر الصحية.