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Health Risk Assessment of Dietary Exposure to Pesticide Residues in Edible Tissue of Tilapia Fish from Lake Manzala, Egypt

Marwa F. Gad*[1], Randa R. Elmorsi[2], Nasr S. Khalil[3], Abdel-Tawab H. Mossa[1]

[1]Pesticide Chemistry Department, Chemical Industries Research Institute, National Research Centre, Giza, Egypt, 33 El Bohouth Street (former El Tahrir St.), P.O. 12622, Dokki, Giza, Egypt.
[2]National Institute of Oceanography and Fisheries (NIOF), Cairo, Egypt
[3]Central Agricultural Pesticides Laboratory (CAPL), Agricultural Research Center (ARC), 7 Nadi El-Seid St., Dokki, Giza, Egypt

Abstract

Synthetic pesticides have adverse effects on both the environment and human health. These chemical compounds can leave residues that contaminate food, water, and soil, thereby posing risks to consumers, workers, and bystanders exposed to pesticides. The primary objective of this study was to determine the levels of pesticide residues in water, fish, and sediment samples collected from various locations in Lake Manzala, Egypt. Additionally, the study aimed to assess the health risks associated with consuming tilapia fish from Lake Manzala, which is known to be contaminated with pesticide residues. Water, sediment, and fish samples were collected from five different locations within Lake Manzala. The samples were analyzed for the presence of pesticide residues, 402 pesticides. For each detected pesticide, the study calculated the Estimated Daily Intake (EDI) and the Hazard Index (HI), considering both individual and combined residues. Results showed that a total of 22 pesticides were detected in water samples, 24 in sediment samples, and 20 in fish samples. The type and concentration of pesticides varied across the sampling locations. Notably, Genka El-Mataria, Bahr El Baqur, and the Old Sea Outlet had the highest pesticide residues. The most common pesticides found in all samples included Cadusafos, Cyprodinil, Thiram, aldicarb-sulfone-NH4+, and cyfluthrin-NH4+. The environmental samples (water, sediment, and fish) contained 42 pesticide residues, spanning different categories: 18 insecticides, 13 herbicides, 9 fungicides, 1 nematicide, and 1 parasitic pesticide. Of the detected residues, 60.71% were from registered pesticides, while 39.29% were from unregistered or discontinued ones. The most prevalent chemical groups were pyrethroids, dinitroaniline, and organophosphorus compounds. The findings of our study indicate that the pesticide concentrations in the fish samples from Lake Manzala were below the acceptable daily intake (ADI) threshold. Furthermore, the health risk index (HI) for each individual pesticide, as well as their combined effect, was lowers than 1 (HI < 1). Consequently, the fish from Lake Manzala are deemed safe for consumption and do not pose any human health hazards related to pesticide exposure.

Keywords: Risk assessment; pesticide residues; Lake Manzala; fish; water; sediment.

1. Introduction

An important module of evaluating the possible adverse effects of pesticides on human health is risk assessment of exposure to pesticide residues [1]. It involves four steps: hazard identification, dose-response assessment, exposure assessment, and risk characterization [2]. Due to pesticide residues in food and water as well as occupational exposure to pesticides, there are currently serious health risks. Therefore, pesticides are subject to strict regulating procedures to ensure their safety and negligible negative effects on the environment and human health [3]. It can damage a number of biological systems and increase the chance of developing chronic diseases [4], [5], [6]. Fishmeal is a traditional and essential component of Egyptian food, as it provides an affordable source of protein for the people. Compared to other animal protein sources, fishmeal is more economical and efficient. According to the Food and Agriculture Organization (FAO), the combined production of aquaculture and capture fisheries contributed to 17% of the total animal protein intake for human consumption worldwide [7].Due to low income in developing countries, fish contributes to more than 30% of the total animal protein intake per person [8].One of the main routes of human exposure to pollutants such as pesticides is through the ingestion

*Corresponding author e-mail: marwagad280@yahoo.com. ; (Marwa F. Gad).
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of fish. Due to the bioaccumulation of pesticide residues and other contaminants in their tissues, fish can also be a major health concern to humans. These toxins can cause a wide range of diseases and disorders, including cancer, neurological damage, hormonal disruption, and immune system impairment [9], [10].

Pesticide residues and other organic pollutants persist and accumulate in fish and ecosystems, where they can pose health hazards to aquatic ecosystems and human consumers [10]. Hence, it is vital to measure and regulate the pesticide residues in fish and water sources. A study assessed the levels and types of organochlorine pesticides in Mugil and Tilapia fish from four lakes in the Egyptian Delta. The results showed that BHC and p,p'-DDT were the most prevalent pesticides in the fish samples from the EI-Manzala, EI-Burullus, Edku, and Maryut lakes. Some fish samples also contained other pesticides, such as lindane, endrin, p,p'-DDT, p,p'-DDE, and p,p'-DDD [11].The tissue samples of the fish species *Clarias gariepinus*, Tilapia zillii, and *Oreochromis niloticus* from the Nile River have been analyzed for pesticide residue. The highest mean level of pesticide residue was found in *Clarias gariepinus*, followed by Tilapia zillii and *Oreochromis niloticus*. The authors found that all detected pesticide residue levels were below the maximum residue limits (MRL).The study concluded that the fish consumption patterns of the consumers did not pose any significant health risk in terms of the tested pesticides [12].

Manzala Lake, located in the northeastern part of the Nile Delta, is the largest and shallowest lake in the region. It lies between the Damietta Branch of the Nile River and the Suez Canal, which connects the Mediterranean Sea and the Red Sea [13]. The lake is exposed to various sources of anthropogenic pollution, such as industrial effluents, oil spills, and sewage systems [13], [14]. Moreover, agricultural runoff from the surrounding lands also affects the water quality of the lake, introducing harmful substances such as pesticides, fertilizers, and organic pollutants[15].These pollutants include heavy metals[16], [17], organochlorine pesticides (OCPs) and polychlorinated biphenyls [11], [12], [18].

This study aimed to measure the levels of pesticide residues in water, fish and sediment samples obtained from Lake Manzala, a brackish water lake in Egypt. The study also assessed the potential health risks for humans who consume fish from this lake.

2. Materials and methods

2.1. The study area's description

Manzala Lake is a coastal lagoon located in the northeastern part of Egypt's Nile Delta, lies between latitude 31°10\ −31°40\ N and longitude 31°50\ −32°25\ E. It covers an area of about 800 km2 and has a maximum depth of 4 m. The lake is bordered by the Mediterranean Sea to the north, the Suez Canal to the east, the Damietta and Tanitic branches of the Nile to the west, and the Suez Canal to the south (Figure 1). The lake is home to various birds and plants, and provides a significant source of fish and salt for the region. The lake also influences the salinity and water level of the Nile Delta [19].

2.2. Sampling

Forty-five samples of water, sediments and fish were collected from five sites (three replicates of each site) in this study.

2.2.1. Water and sediments samples

Lake Manzala was selected in the current study. Water samples were taken from the surface water at 50 cm depth during the study period. While the sediment samples were collected from the same sites. The lake was divided into five sampling sites based on the degree of wastewater impact and the type of effluent sources. Site 1 (Genka-El-Mataria) was located near Ramsis and Hadus drains, which carried agricultural waste. Site 2 (Legan) was close to Matariya drain, another source of agricultural waste. Site 3 (Bahr El-Baqur) was influenced by New Bahr Elbaqur drain, which discharged mixed wastes from urban and industrial areas. Site 4 (Old sea outlet) had two effluent sources: A. El-Rasoah and El- Qabuty, which brought seawater from El-Gamil canal, and B. Alhuria, which delivered domestic waste. Site 5 (New sea outlet) was the least affected by wastewater, as it only received seawater from El-Gamil canal.

Figure 1: Manzala Lake and sample sit maps map obtained from Google maps

2.2.2. Fish sampling

The tilapia fish (*Oreochromis niloticus*) (Figure 2) were caught from five sample sites of different three locations Legan (site 1), Elboghez (site 2) and Genka-El-Mataria (site 3) from El Manzala Lake. The samples were brought to the lab as soon as feasible and stored there for a week while frozen at -20 ºC.

Figure 2: Tilapia fish samples

2.3. Extraction and clean up

Samples of fish [20], water [21], and sediment [22] were collected and subjected to routine extraction protocol according to the QuEChERS method [23] with some modifications. Fish muscles were ground, 10 g of fish muscle, sediment, or water were transferred to a 50 mL polypropylene centrifuge tube. Ten milliliters of acetonitrile were added, homogenized and the following compounds were added (4.0 g $MgSO_4$ anhydrous; 1.0 g NaCl, 1.0 g trisodium citrate dehydrate, and 0.5 g disodium hydrogen citrate). After shaking for 1 min, samples were centrifuged (4800 rpm for 5 min) and then 200 µL of supernatant were diluted 5 times by acetonitrile (800 µL) of each sample and filtrated using syringe filter (0.2 µm PTFE). Then the equivalent concentration of pesticide residues in all samples (mg/kg or letter) was calculated. The results showed that the levels of pesticides residues in all samples were within the acceptable limits established by the relevant authorities [24], [25].

2.4. LC – MS/MS analysis and MS procedures

LC – MS/MS analysis was carried out using a Thermo Scientific TM Dionex Ultimate TM 300 RS UHPLC + focused system coupled to a TSQ Altis triple quadruple mass spectrometer (Thermo Fisher Scientific Austin, TX, USA). Trace finder software (version 4.1) was used for instrument control analysis, data acquisition and reporting. Chromatographic separation was carried out on a Hypersil Gold TM C18 column (100 x 2.1 mm, 3-µm film thickness; (Thermo Fisher Scientific Austin, TX, USA).

2.4.1. LC–MS/MS procedure

All reagents and solvents used were of analytical or higher grade and purchased from Sigma Aldrich (Merck KGaA) (LC – Grade). Mobile phase A was 10: 90 methanol: water (v/v) and mobile phase B was 90: 10 methanol: water (v/v); both mobile phases contained 5 mM ammonium formate and 0.1 % formic acid. Chromatographic separation was performed at mobile phase flow rate 0.3 ml / min and column temperature were maintained at and 40ºC. Agradient elution program was used starting from 0 – 12 min 100% A, 12 – 14 min 0% A, 14.1 – 20 min 100% A. Ion production in mass spectrometry was achieved applying a voltage in positive (H-ESI+) mode. The positive ion spray voltage was 3800 V. The sheath and Aux gas were 40 and 10 Arb, respectively. The ion transfer tube and vaporizer temperature were 325ºC, respectively. HypersilGoldTM C18 column was used.

2.5. Method validation

The LC–MS/MS method was validated with respect to specificity, linearity, sensitivity, precision, accuracy, matrix effects, and recovery for 402 pesticides. Limits of detection (LODs) was determined from six independently spiked pesticide concentrations (1, 5, 10, 25, 50, and 100 µg/L). LODs for studied pesticides were calculated based on the stander division of the repeatability study for the LOQ Level. The LOQs varied for each pesticide, ranging from 0.0015 to 0.012 mg/kg. The pesticide residues analysis was conducted by the Pesticide Chemistry Department of the National Research Centre in Cairo, Egypt, in collaboration with the National Center for Monitoring Pesticide Residues & Pollutants (NCPR) at Central Agricultural Pesticides Laboratory (CAPL), Ministry of Agriculture, Giza, Egypt.

2.6. Health risk assessment

2.6.1. Dietary risk assessment of fish consumption

Exposure assessment of pesticide residues

For dietary risk assessment of fish consumption, estimated daily intake (EDI) of pesticides (Pc) was calculated by using this equation:

EDI = Pc (mg/kg fish) x fish consumption rate (mg/kg b. wt./ day)

Where, EDI is estimated daily intake, Pc.is pesticide contents (mg/kg) in the fish flesh in wet weight. According to World Fish, the average consumption rate of fish was 64.38 g of adult person per day [26]. The mean body weight for adult consumer is 70 kg and the average fish consumption is 0.9197 mg/kg b. wt. day [27].

2.6.2. Risk characterization of pesticide residues

Risk of dietary exposure to single pesticide

Risk quotient (RQ) was calculated by using this equation:

RQ = EDI/ ADI

Where, RQ is risk quotient, EDI is estimated daily intake (mg/kg) and ADI is acceptable daily intake (mg/kg. b. wt. day) [28], [29]. Unacceptable chronic health risk of fish consumption found at RQ value more than 1 (RQ > 1), while minimal health risk at RQ less than 1 (RQ < 1) [25], [30].

2.6.3. Risk of dietary exposure to mixture of pesticides

Risk of dietary exposure to chemical mixtures (Pc) were related to risk quotient (RQ) and risk index (RI) and performed according to Goumenou and Tsatsakis [31] by using this equation:

$$RI = \sum_{i}^{n} (RQ)i$$

Where RI is risk index for a mixture of n-pesticides and RQ is risk quotient of Pc.

The Egyptian Codex [32]provides the acceptable daily intake (ADI, µg/kg. b.wt.) for different pesticides. The National Food Safety Authority (NFSA) states that if there is no available data on the maximum residue limits (MRL) of a pesticide, the default value of 0.01 mg/kg should be applied. Therefore, this value was used as the MRL for any pesticide that lacked such data.

3. Results

3.1. Pesticide residues in water samples

A pesticide residue analysis was performed on the water samples collected from five sites in Lake Manzala: Genka-El-Mataria, Legan, Bahr El-Baqur, Old sea outlet and new sea outlet (Table 1). The analysis identified 22 different pesticides belonging to various groups, with each site having a different number of detected pesticides: Genka-El-Mataria had 10, Legan had 9, Bahr El-Baqur had 11, Old sea outlet had 12 and new sea outlet had 11. The pesticide residue levels also varied among the sites, with the highest residues being cyfluthrin-NH4 (0.3244 ppm), aldicarb-sulfone-NH4+ (0.1095 ppm), aldicarb-sulfone-NH4+ (0.5108 ppm), abamectin (B1a) (4.388 ppm), and aldicarb-sulfone-NH4+ (0.1751 ppm), in the samples from Genka-El-Mataria, Legan, Bahr El-Baqur, Old sea outlet and new sea outlet, respectively. The most frequently detected pesticides were Cadusafos, Cyprodinil, and Thiram, which were present in all the samples.

3.2. Pesticide residues in sediment samples

The sediment samples from five sites in Lake Manzala: Genka-El-Mataria, Legan, Bahr El-Baqur, Old sea outlet and new sea outlet (Table 2) were subjected to a pesticide residue analysis. The analysis revealed the presence of 24 different pesticides from various groups, with each site having a distinct number of detected pesticides 11 at Genka-El-Mataria, 7 at Legan, 19 at Bahr El-Baqur, 8 at Old sea outlet and 8 at new sea outlet. The levels of pesticide residues also differed among the sites, with the highest residues being aldicarb-sulfone-NH4+ (0.3385 ppm), aldicarb-sulfone-NH4+ (0.1577 ppm), tolylfluanid (6.729 ppm), cadusafos (0.0354 ppm), and cyfluthrin-NH4 (1.049 ppm) in the samples from Genka-El-Mataria, Legan, Bahr El-Baqur, Old sea outlet and new sea outlet, respectively. The most commonly found pesticides were aldicarb-sulfone-NH4+, cyprodinil, glufosinate, permethrin and thiram, which were detected

Table 1. Pesticides residues (ppm) in water samples collected from different sites in Manzala Lake.

Compounds	Pesticides residues (ppm)				
	Site				
	Genka-El-Mataria	Legan	Bahr El-Baqur	Old sea outlet	New sea outlet
Abamectin (B1a)	n.d.	n.d.	n.d.	4.388	n.d.
Aldicarb-sulfone-NH4+	n.d.	0.1095	0.5108	0.1938	0.1751
Alpha-cypermethrin-NH4+	0.0048	n.d.	n.d.	n.d.	n.d.
Amisulbrom	n.d.	n.d.	0.0062	n.d.	n.d.
Cadusafos	0.0039	0.0066	0.0876	0.1305	0.0748
Cyfluthrin-NH4	0.3244	n.d.	n.d.	0.0050	n.d.
Cypermethrin-NH4+	0.0065	n.d.	n.d.	n.d.	n.d.
Cyprodinil	0.0078	0.0068	0.0065	0.0074	0.0076
Diphenylamine	0.0040	n.d.	n.d.	0.0049	n.d.
EPN	0.00258	n.d.	0.0180	0.0193	n.d.
Glufosinate	n.d.	n.d.	0.0041	n.d.	0.0062
Halosulfuron-methyl	n.d.	n.d.	n.d.	0.0047	n.d.
Methoxyfenozide	n.d.	n.d.	n.d.	0.0069	0.0040
Milbemectin A3	n.d.	0.00277	0.00462	n.d.	0.0339
Moxidectin	0.0186	n.d.	0.0360	n.d.	0.0155
Oxyfluorfen	0.0096	n.d.	n.d.	n.d.	0.0058
Pendimethalin	n.d.	0.0063	n.d.	n.d.	n.d.
Permethrin	n.d.	0.0088	0.0110	0.0071	0.0069
Pyridalyl	n.d.	0.0046	0.0047	n.d.	n.d.
Thiophanate-methyl	n.d.	n.d.	n.d.	0.0059	n.d.
Thiram	0.0079	0.0079	0.0079	0.0079	0.0079
Topramezone	n.d.	0.0119	n.d.	n.d.	0.0119

Not detected (n.d.).

Table 2. Pesticides residues (ppm) in sediment samples collected from different sites in Manzala Lake.

Compounds	Pesticide residues (ppm)				
	Site				
	Genka-El-Mataria	Legan	Bahr El-Baqur	Old sea outlet	New sea outlet
Aldicarb-sulfone-NH4+	0.3385	0.1577	0.0649	0.0183	0.0195
Alpha-cypermethrin-NH4+	n.d.	n.d.	0.0182	n.d.	n.d.
Amitraz	n.d.	n.d.	0.0211	n.d.	n.d.
Cadusafos	0.0339	n.d.	0.1109	0.0354	0.0556
Chlorpyriphos	5.141	n.d.	47.005	n.d.	n.d.
Cyfluthrin-NH4	n.d.	n.d.	n.d.	n.d.	1.049
Cyhalothrin-NH4	n.d.	n.d.	0.0152	n.d.	n.d.
Cyprodinil	0.0084	0.0089	0.0077	0.0093	0.0104
Diphenylamine	0.0061	n.d.	0.0151	n.d.	0.0049
EPN	0.0763	n.d.	n.d.	n.d.	n.d.
Esfenvalerate	n.d.	n.d.	0.0785	n.d.	n.d.
Fenoxaprop-p-ethyl	n.d.	n.d.	0.5142	n.d.	n.d.
Fenvalerate	n.d.	n.d.	0.0785	n.d.	n.d.
Glufosinate	0.0060	0.0048	n.d.	0.0045	n.d.
Methoxyfenozide	n.d.	n.d.	0.0057	n.d.	n.d.
Milbemectin A3	0.0270	n.d.	0.0177	n.d.	n.d.
Milbemectin A4	n.d.	n.d.	0.0278	n.d.	n.d.
Permethrin	0.0089	0.0075	0.0409	0.0097	0.0083
Pyridalyl	0.0044	n.d.	0.0059	n.d.	n.d.
Thiobencarb	n.d.	n.d.	n.d.	0.0068	n.d.
Thiophanate-methyl	n.d.	0.0059	n.d.	n.d.	n.d.
Thiram	0.0080	0.0079	0.0080	0.0083	0.0078
Tolylfluanid	n.d.	n.d.	6.729	n.d.	n.d.
Topramezone	n.d.	0.00119	0.00119	0.0118	0.0119

Not detected (n.d.)

3.3. Pesticide residues in fish samples

The pesticide residue analysis revealed 20 different types of pesticides in the fish samples from Legan, one of the three locations in Lake Manzala where the samples were collected (Table 3). The other two locations were Elboghez (Table 4) and Genka-El-Mataria (Tables 5). As shown in Table 3, the samples from Legan contained different levels and groups of pesticide residues, with 20 pesticides detected. The most abundant residue was alpha-cypermethrin-NH4+ with an average concentration of 0.015 ppm, while the most common pesticides were aldicarb-sulfone-NH4+, cadusafos, cyprodinil, diphenylamine, thiram and topramezone, which were found in all the samples. The pesticide residues varied from 0.015 ppm to 0.000 ppm, and most of them did not exceed the maximum residue limit (MRL) except for aldicarb-sulfone-NH4+, alpha-cypermethrin-NH4+ and cypermethrin-NH4+.Table 4 shows the results of pesticide residue analysis for the samples collected from Elboghez. 24 pesticides were detected, belonging to different classes and groups. The highest residue level was found for cypermethrin-NH4+ with an average concentration of 0.04018 ppm, while the most frequently detected pesticides were alpha-cypermethrin-NH4+, cadusafos, cypermethrin-NH4+, cyprodinil, glufosinate, pendimethalin, thiram and topramezone, which were present in all the samples. The residue levels ranged from 0.04018 ppm to 0.00034 ppm, and most of them were below the maximum residue limit (MRL) established by the relevant authorities. However, some pesticides exceeded the MRL, namely aldicarb-sulfone-NH4+, cyfluthrin-NH4, cypermethrin-NH4+, cyprodinil, EPN and pendimethalin. As shown in Table 5, the samples from Genka-El-Mataria had various types and amounts of pesticide residues, with 20 pesticides identified. The residue with the highest average concentration was EPN (0.0341 ppm), while the most frequently detected pesticides were alpha-cypermethrin-NH4+, cadusafos, cypermethrin-NH4+, cyprodinil, EPN, permethrin, thiram and topramezone, which were present in all the samples. The pesticide residues ranged from 0.0341 ppm to 0.0003 ppm, and most of them were below the maximum residue limit (MRL) except for aldicarb-sulfone-NH4+, cyprodinil, EPN, and pendimethalin.

3.4. An overview of pesticide residues statues in water, sediment and fish

We found 42 different pesticide residues, including one endectocide for animal parasites, in various environmental samples (water, sediment, and fish) from Lake Manzala (Table 6). We detected 18 insecticides, of which 11 were still registered or approved for agricultural use, while the other seven were unregistered or discontinued. The registered or used insecticides represented 61.11% of the total insecticide residues, while the unregistered insecticides represented 38.89%. The most prevalent insecticide residues were pyrethroids, with eight insecticide residues, followed by organophosphorus with two residues. The remaining insecticides belonged to seven other chemical groups. Our findings demonstrated that 13 herbicide residues from 11 different chemical groups were found in fish, sediment, and water samples. Only eight of these 13 herbicides are now registered or approved for use in agriculture; the other five were either unregistered or unapproved. Herbicides that were approved and unapproved account for 61.54% and 38.46% of total herbicide residues, respectively. Dinitroaniline was the chemical group that was most commonly found, followed by others. We detected nine different types of fungicides in the samples, each belonging to a distinct chemical group. However, only five of these fungicides had been approved for use, while the remaining four had not. The majority of the fungicides residues (55.56%) came from the approved ones, while the rest (44.44%) came from the unapproved ones. In addition, we found a nematicide in both water and fish samples and an endectocide in a water sample (Table 6). Table 7 summarizes the results of pesticide residue analysis in water, soil and fish samples. The analysis included 42 compounds, which were grouped into five categories based on their mode of action: pesticides (18 compounds, 42.857%), herbicides (13 compounds, 30.952%), fungicides (9 compounds, 21.429%), nematode (one compound, 2.381%) and parasitic pesticide (one compound, 2.381%). Out of the detected residues, 26 pesticides are registered and in use, while 16 pesticides are unregistered, representing 61.905% and 38.095% of the total respectively.

Table 3. Pesticide residues (mg/kg) in muscles fish of samples collected from different sites of Legan from El Manzala Lake.

Compounds	Residues (mg/kg)					Mean (mg/kg)	Sample > MRL*	Single pesticide			Mixture of pesticides		
	Sample no.							EDI (mg/kg. b.wt)	ADI (mg/kg. b.wt)	RQ	EDI (mg/kg. b.wt)	ADI (mg/kg. b.wt)	HI
	1	2	3	4	5								
Aldicarb-sulfone-NH4+	0.0073	0.0199	0.0107	0.0148	0.0152	0.014	+	0.012	0.02	0.6245			
Alpha-cypermethrin-NH4+	n.d.	0.021	0.0298	0.0152	0.0102	0.015	+	0.014	0.02	0.7008			
Amisulbrom	n.d.	n.d.	n.d.	0.0068	n.d.	0.001	-	0.001	0.1	0.0125			
Amitraz	n.d.	0.0031	0.0022	0.0037	0.0013	0.002	-	0.002	0.003	0.6315			
Bupirimate	n.d.	0.0109	0.0047	n.d.	n.d.	0.003	-	0.003	0.05	0.0574			
Cadusafos	0.00013	0.00013	0.00015	0.00017	0.00014	0.000	-	0.000	0.0004	0.3260			
Cypermethrin-NH4+	n.d.	0.01003	0.0496	0.0552	0.01236	0.025	+	0.023	0.05	0.4679			
Cyprodinil	0.0103	0.0101	0.0087	0.0107	0.0104	0.010	-	0.009	0.03	0.3078			
Deltamethrin-NH4+	n.d.	0.0047	n.d.	n.d.	n.d.	0.001	-	0.001	0.01	0.0865			
Desmedipham	n.d.	0.0146	0.0053	n.d.	n.d.	0.004	-	0.004	0.016	0.2288	0.105	2.9934	0.035
Diphenylamine	0.0052	n.d.	0.014	0.0056	0.0045	0.006	-	0.005	0.075	0.0719			
EPN	n.d.	n.d.	0.0137	n.d.	n.d.	0.003	-	0.003	--	-			
Glufosinate	0.0047	0.0067	0.0045	n.d.	0.0058	0.004	-	0.004	0.021	0.1901			
Imazapyr	n.d.	n.d.	n.d.	0.0336	n.d.	0.007	-	0.006	2.5	0.0025			
Oxadiargyl	n.d.	0.0072	0.00104	n.d.	0.008	0.003	-	0.003	0.008	0.3734			
Permethrin	n.d.	0.0089	0.0084	0.0084	0.0086	0.007	-	0.006	0.05	0.1262			
Thiobencarb	0.00148	n.d.	n.d.	n.d.	n.d.	0.000	-	0.000	0.009	0.0302			
Thiophanate-methyl	n.d.	n.d.	n.d.	0.0059	n.d.	0.001	-	0.001	0.02	0.0543			
Thiram	0.008	0.0079	0.0079	0.0079	0.0079	0.008	-	0.007	0.01	0.7284			
Topramezone	0.0011	0.00112	0.00101	0.00104	0.00101	0.001		0.001	0.001	0.9718			

An average fish consumption is 0.9197 g/kg b.wt. day was used. Not detected (n.d.), estimated daily intake (EDI). Risk quotient (RQ), Health Risk Index (HI), acceptable daily intake (ADI). *The National Food Safety Authority (NFSA) states that if there is no available data on the maximum residue limits (MRL) of a pesticide, the default value of 0.01 mg/kg should be applied **(ANFS, 2021)**

Table 4. Pesticide residues (mg/kg) in muscles fish of samples collected from different sites of Elboghez from El Manzala Lake.

Compounds	Pesticide residues (mg/kg) Sample no. 1	2	3	4	5	Mean (mg/kg)	Sample > MRL *	Single pesticide EDI (mg/kg. b.wt)	ADI (mg/kg. b.wt)	RQ	Mixture of pesticides EDI (mg/kg. b.wt)	ADI (mg/kg. b.wt)	HI
Abamectin (B1a)	n.d.	0.0042	n.d.	n.d.	n.d.	0.00084	-	0.0008	0.0012	0.6438			
Aldicarb-sulfone-NH4+	0.009	n.d.	0.0027	0.0681	0.021	0.02016	+	0.0185	0.02	0.9271			
Alpha-cypermethrin-NH4+	0.0029	0.0029	0.00325	0.00268	0.0073	0.003806	-	0.0035	0.02	0.1750			
Amisulbrom	n.d.	0.0052	n.d.	0.0108	n.d.	0.0032	-	0.0029	0.1	0.0294			
Amitraz	0.0056	0.0014	0.00108	n.d.	0.00124	0.001864	-	0.0017	0.003	0.5714			
Butralin	n.d.	0.004	n.d.	0.0047	0.0057	0.00288	-	0.0026	0.01	0.2649			
Cadusafos	0.00021	0.00016	0.00012	0.00106	0.00019	0.00034	-	0.0003	0.0004	0.8029			
Chlorpyriphos	n.d.	n.d.	0.0046	n.d.	n.d.	0.00092	-	0.0008	0.003	0.2820			
Clopyralid	n.d.	n.d.	n.d.	0.0269	n.d.	0.00538	-	0.0049	0.15	0.0330			
Cyfluthrin-NH4	0.1047	n.d.	n.d.	n.d.	n.d.	0.02094	+	0.0193	0.15	0.1284			
Cypermethrin-NH4+	0.0588	0.0751	0.0367	0.0227	0.0076	0.04018	+	0.0370	0.05	0.7391			
Cyprodinil	0.0111	0.0103	0.0111	0.0112	0.012	0.01114	+	0.0102	0.03	0.3415	0.2023	1.0126	0.1998
Deltamethrin-NH4+	n.d.	0.0085	0.0271	n.d.	n.d.	0.00712	-	0.0065	0.01	0.6548			
Diphenylamine	n.d.	0.0076	0.0084	0.0062	n.d.	0.00444	-	0.0041	0.075	0.0544			
EPN	n.d.	n.d.	n.d.	0.0647	0.0541	0.02376	+	0.0219	-	-			
Glufosinate	0.0044	0.0055	0.0041	0.004	0.0044	0.00448	-	0.0041	0.021	0.1962			
Hymexazol	n.d.	0.0077	n.d.	n.d.	n.d.	0.00154	-	0.0014	0.17	0.0083			
Oxadiargyl	0.0123	0.0187	n.d.	n.d.	0.0086	0.00792	-	0.0073	0.008	0.9105			
Pendimethalin	0.0048	0.006	0.0061	0.1778	0.022	0.04334	+	0.0399	0.125	0.3189			
Permethrin	0.005	n.d.	0.0035	0.004	0.0046	0.00342	-	0.0031	0.005	0.6291			
Pyridalyl	n.d.	n.d.	0.0049	n.d.	n.d.	0.00098	-	0.0009	0.03	0.0300			
Thiophanate-methyl	0.0059	n.d.	n.d.	n.d.	0.0059	0.00236	-	0.0022	0.02	0.1085			
Thiram	0.008	0.0081	0.0079	0.008	0.0082	0.00804	-	0.0074	0.01	0.7394			
Topramezone	0.0011	0.00102	0.00102	0.00102	0.00101	0.00104	-	0.0010	0.001	0.9517			

An average fish consumption is 0.9197 g/kg b.wt. day was used. Not detected (n.d.), estimated daily intake (EDI). Risk quotient (RQ), Health Risk Index (HI), acceptable daily intake (ADI). *The National Food Safety Authority (NFSA) states that if there is no available data on the maximum residue limits (MRL) of a pesticide, the default value of 0.01 mg/kg should be applied **(ANFS, 2021)** .

Table 5. Pesticide residues (mg/kg) in muscles fish of samples collected from different sites of Genka-El-Mataria from El Manzala Lake.

Compounds	Pesticide residues (mg/kg) Sample no. 1	2	3	4	5	Mean (mg/kg)	Sample > MRL*	Single pesticide EDI (mg/kg. b.wt)	Single pesticide ADI (mg/kg. b.wt)	Single pesticide RQ	Mixture of pesticides EDI (mg/kg. b.wt)	Mixture of pesticides ADI (mg/kg. b.wt)	Mixture of pesticides HI
Abamectin (B1a)	n.d.	n.d.	0.004	n.d.	n.d.	0.0008	-	0.0007	0.0012	0.6131			
Aldicarb-sulfone-NH4+	0.021	n.d.	0.0201	n.d.	0.0171	0.0116	+	0.0107	0.02	0.5353			
Alpha-cypermethrin-NH4+	0.0073	0.0071	0.0129	0.014	0.0051	0.0092	-	0.0085	0.02	0.4267			
Amitraz	0.0012	0.006	0.0012	0.0071	n.d.	0.0031	-	0.0029	0.003	0.9559			
Butralin	0.0057	n.d.	n.d.	n.d.	n.d.	0.0011	-	0.0010	0.01	0.1048			
Cadusafos	0.0001	0.0002	0.0005	0.0004	0.00059	0.0003	-	0.0004	0.0004	0.9179			
Cypermethrin-NH4+	0.0076	0.0074	0.0128	0.0147	0.0054	0.0095	-	0.0088	0.05	0.1762			
Cyprodinil	0.012	0.0108	0.0128	0.0112	0.0124	0.0118	+	0.0109	0.03	0.3630			
Deltamethrin-NH4+	n.d.	n.d.	n.d.	0.0111	n.d.	0.0022	-	0.0020	0.01	0.2042			
Diphenylamine	n.d.	0.0069	n.d.	0.0055	0.004	0.0032	-	0.0030	0.075	0.0402	0.1172	2.9576	0.040
EPN	0.0541	0.0092	0.0557	0.0263	0.0256	0.0341	+	0.0314	-	-			
Glufosinate	0.0044	n.d.	0.0049	n.d.	n.d.	0.0018	-	0.0017	0.021	0.0815			
Imazapyr	n.d.	n.d.	0.0243	n.d.	n.d.	0.0048	-	0.0045	2.5	0.0018			
Oxadiargyl	0.0086	0.0043	n.d.	n.d.	n.d.	0.0025	-	0.0024	0.008	0.2966			
Oxyfluorfen	n.d.	n.d.	0.0017	0.0011	n.d.	0.0005	-	0.0005	0.003	0.1735			
Pendimethalin	0.022	0.0045	0.0234	0.007	n.d.	0.0113	+	0.0105	0.125	0.0837			
Permethrin	0.0086	0.0085	0.0084	0.0086	0.0084	0.0085	-	0.0078	0.05	0.1563			
Thiophanate-methyl	0.0059	n.d.	n.d.	n.d.	n.d.	0.0011	-	0.0011	0.02	0.0543			
Thiram	0.0082	0.0079	0.0079	0.0079	0.0083	0.0080	-	0.0074	0.01	0.7394			
Topramezone	0.0010	0.0010	0.0010	0.0011	0.00101	0.0010	-	0.0010	0.001	0.9683			

An average fish consumption is 0.9197 g/kg b.wt. day was used. Not detected (n.d.), estimated daily intake (EDI). Risk quotient (RQ), Health Risk Index (HI), acceptable daily intake (ADI). *The National Food Safety Authority (NFSA) states that if there is no available data on the maximum residue limits (MRL) of a pesticide, the default value of 0.01 mg/kg should be applied **(ANFS, 2021)** .

Table 6. Common names and chemical classes of the pesticide residues found in fish, sediment, and water samples from El Manzala Lake and their registration statuses in Egypt.

Pesticide type / Chemical group	No.	Common name	Registration status*	
			Approved (√)	Unapproved (x)
Insecticide				
Pyrethroids	1.	Alpha-cypermethrin-NH4+	√	-
	2.	Cyfluthrin-NH4	√	-
	3.	Cyhalothrin-NH4	√	-
	4.	Cypermethrin-NH4+	√	-
	5.	Deltamethrin-NH4+	√	-
	6.	Esfenvalerate	-	X
	7.	Fenvalerate	-	X
	8.	Permethrin	-	X
Organophosphate	9.	Chlorpyriphos	-	X
	10.	EPN	-	X
Carbamate	11.	Aldicarb-sulfone-NH4+	-	X
Avermectin	12.	Abamectin (B1a)	√	-
Amidin	13.	Amitraz	-	X
Pyridyl	14.	Pyridalyl	√	-
Diacylhydrazine	15.	Methoxyfenozide	√	-
Macrocyclic lactone	16.	Milbemectin A3	√	-
	17.	Milbemectin A4	√	-
Diacylhydrazine	18.	Methoxyfenozide	√	-
Number of insecticides		18	11	7
	Percentage (%)		61.11	38.89
Herbicide				
Dinitroaniline	19.	Butralin	√	-
	20.	Pendimethalin	√	-
	21.	Imazapyr	-	X
Organophosphate	22.	Glufosinate	√	-
Thiocarbamate	23.	Thiobencarb	√	-
Sulfonylurea	24.	Halosulfuron-methyl	-	X
Imidazolinone	25.	Imazapyr	-	X
Pyridine	26.	Clopyralid	√	-
Phenyl carbamate	27.	Desmedipham	√	-
2-(4-aryloxyphenoxy) propionic acids	28.	Fenoxaprop-p-ethyl	√	-
Pyrazole	29.	Topramezone	-	X
Oxadizole	30.	Oxadiargyl	-	X
Diphenyl-ether	31.	Oxyfluorfen	√	-
Number of insecticides		13	8	5
	Percentage (%)		61.54	38.46
Fungicide				
Sulfonamide	32.	Amisulbrom	√	-
Pyrimidinol	33.	Bupirimate	√	-
pyrimidine sulfamates	34.	Bupirimate	√	-
Anilinopyrimidine	35.	Cyprodinil	√	-
Diphenyl amine	36.	Diphenylamine	-	X
Heteroaromatic (oxazoles)	37.	Hymexazol	√	-
Benz imidazole	38.	Thiophanate-methyl	-	X
Dimethylethiocarbamate	39.	Thiram	-	X
polyvalent sulfamide	40.	Tolylfluanid	-	X
Total		9	5	4
	Percentage (%)		55.56	44.44
Nematicide				
Organophosphate	41.	Cadusafos	√	-
Total		1	1	-
	Percentage (%)		100	0.00
Endectocide "drug"				
Macrocyclic lactone	42.	Moxidectin	-	X
Moxidectin is a type of endectocide, which means it can target both endo- and ecto-parasites It can kill a wide range of parasites, both internal and external, that affect animals. They work against worms, insects, and mites that can cause diseases and infections in animals.				
Total		1	-	1
	Percentage (%)		0.00	100

*The table lists the pesticides that are approved (√) or unapproved (x) for use in agriculture according to the Approved recommendations for agriculture pest control 2023 issued by Ministry of Agriculture, Egypt. Any metabolites of pesticides are considered to have the same status as the approved or unapproved active ingredient.

Table 7. The total number and percentage of pesticides found in fish, sediment, and water samples taken from El Manzala Lake.

Pesticides	Number	%	Registration status*	
			Approved	Unapproved
Insecticides	18	42.857	11	7
Herbicides	13	30.952	8	5
Fungicides	9	21.429	5	4
Nematicides	1	2.381	1	0
Endectocide	1	2.381	1	0
Total	**42**	**100**	**26**	**16**
Percentage (%)		**100**	**61.905**	**38.095**

*The table lists the number of pesticides that are approved or unapproved for use in agriculture according to the Approved recommendations for agriculture pest control 2023 issued by Ministry of Agriculture, Egypt.

3.5. Risk of dietary exposure to single and mixture of pesticide residues in fish

The risk quotient (RQ) is a measure of the potential health effects of consuming fish contaminated with pesticide residues. The RQ values of the fish samples from five locations in Lake Manzala (Legan, Elboghez, and Genka-El-Mataria) were calculated and compared with the acceptable daily intake (ADI) limit of the pesticides (Tables 3,4,5). The pesticide residues in the fish samples were also within the ADI limit, suggesting that the exposure to the pesticides was below the level that could cause adverse health effects. Our results showed that the risk quotient (RQ) of all pesticide residues and the risk index (HI) of their mixture was below 1 (RQ and HI < 1), which means that eating fish from this lake does not pose any health threats, either from individual pesticides or from the total amount of residues found.

4. Discussion

4.1. Discussion of pesticide residues statues in water, sediment and fish

Synthetic pesticides are used to protect crops, animals, and humans while reducing pest damage. These chemicals can increase agricultural product productivity and quality, protect humans from pest-borne diseases, and improve the appealing appearance of rural as well as urban settings [1], [5], [6]. Synthetic pesticides can negatively affect the environment and human health. They may leave residues that pollute food, water, and soil, risking the health of customers, workers, and bystanders who are exposed to pesticides [12], [14], [18], [30], [33]. Additionally, they have the potential to disrupt both aquatic and terrestrial ecosystems' biodiversity and ecological balance [34], [35]. They can accumulate in the tissues of animals and humans through ingestion of polluted water or food. Mwevura et al [36] indicated that about 80% of human exposure to pesticide residues results from eating tainted food.

In fact, the majority of previous studied focused on measuring the levels of organochlorine pesticides in Lake Manzala[37], [38], [39], [40], [41]. This study is one of the first to monitor the presence of various types of pesticides from different chemical groups in water, sediment and fish of the lake Manzala. In the current study, a full assessment of the pesticide contamination in water samples revealed the presence of 22 different pesticides from various classes and their varying levels and types across the sampling locations. The samples from Genka-El-Mataria, Legan, Bahr El-Baqur, Old sea outlet and new sea outlet had the highest residues of cyfluthrin, aldicarb, and abamectin. The most frequently detected pesticides were Cadusafos, Cyprodinil, and thiram, which were found in all the samples. These pesticide residues obtained from agricultural drainage water and human activities that pollute the lake. The lake receives industrial waste, oil spills, and sewage discharge from different sources, which deteriorate its water quality and threaten its ecosystem [13], [14].

Other studies showed that the lake is also affected by agricultural runoff from the surrounding lands, which introduces harmful substances such as pesticides, fertilizers, and organic pollutants into the lake. These pollutants include heavy metals, organochlorine pesticides (OCPs) and polychlorinated biphenyls [11], [12], [15], [16], [17], [18]. The results of the study revealed that 24 different pesticides were detected in the sediment samples collected from five different locations in Lake Manzala: Genka-El-Mataria, Legan, Bahr El-Baqur, Old Sea outlet and new sea outlet. The highest number of pesticides (19) was found in the samples from Legan, followed by Genka-El-Mataria (11), Old Sea outlet (8), new sea outlet (8) and Bahr El-Baqur (7).

The most prevalent pesticides in the samples were aldicarb, tolylfluanid, cadusafos, and cyfluthrin, which showed high concentrations in some locations. The water and sediment samples from the lake were analyzed for the presence of 22 different pesticides. The analysis revealed that the water samples contained residues of 16 pesticides, while the sediment samples had residues of 24 pesticides.

Among these, 16 pesticides were common to both water and sediment, 6 pesticides were exclusive to water, and 8 pesticides were exclusive to sediment. The variation in the quantity and quality of pesticide residues could be attributed to the recent improvements in the lake's sanitation and modernization, as well as to the physical characteristics of pesticides such as their stability, absorption, solubility and others. Several previous studies have reported the presence of various chemical groups of pesticide residues in the water and sediment samples of Lake Manzala, a major freshwater lake in Egypt [42], [43], [44], [45]. These studies have emphasized the possible environmental and health impacts of the lake's contamination by pesticides, which are widely used in the surrounding agricultural areas. Fish can absorb pesticides from their feed, which can lead to the presence of pesticide residues in fish products. Therefore, it is important to evaluate the transfer of pesticide residues to fish products. Studies are conducted to determine pesticide residues in fish breeding sites, caught fish, and fish-based products are necessary. Studies on the surveillance of these pesticide residues show the level of consumer risk and the standard of fish-based products [46],[1], [4], [47]. In the current study, the presence of pesticide residue in fish samples from three different sites (Legan, Elboghez and Genka-El-Mataria) was investigated in this study.

The results showed that 20, 24 and 20 different pesticides were detected in the respective sites. The most common pesticides that were found in all the sites were aldicarb-sulfone-NH4+, cadusafos, cyprodinil, thiram and topramezone. The concentrations of these pesticides ranged from 0.015 ppm to 0.000 ppm. Some of the pesticides exceeded the maximum residue limit (MRL) set by the relevant authorities, such as aldicarb-sulfone-NH4+, alpha-cypermethrin-NH4+, cypermethrin-NH4+, cyfluthrin-NH4+, cyprodinil, EPN and pendimethalin. The highest concentration of alpha-cypermethrin-NH^{4+} was observed in the Legan samples, while the highest concentration of EPN was observed in the Genka-El-Mataria samples. These results revealed some variations in the number and identity of the pesticides found in each sample. Fish from Legan had residues of thiobencarb and bupirimate, while fish from Elboghez had residues of abamectin, butralin, chlorpyriphos, clopyralid, hymexazol, pendimethalin and pyridalyl. Fish from Genka-El-Mataria had residues of oxyfluorfen only. These differences could be attributed to the different sources of water that feed the lake, which are agricultural waste for Genka-El-Mataria and Legan, and domestic waste and seawater for Elboghez.

Residues of pyrethroids (eight) and organophosphorus (two) insecticides were the most common insecticides groups found in water, sediment and fish samples. These pesticides are the most commonly used in agriculture for insect pest control. Therefore, results of different studies have shown the presence of theses insecticide residues in different samples at different levels [48], [49], [50]. In the current study, 42 pesticide residues were detected in water, sediment, and fish samples from Lake Manzala. These pesticides included 18 insecticides (11 registered or approved for agricultural use represented 61.11% and 7 unregistered or discontinued represented 38.89 %.). 13 herbicides also, were detected in samples of water, sediment, fish and eight of them are still used (61.54% of total herbicides residues), and five are stop of uses (38.46% of total herbicides residues). 9 fungicides residues were detected and 55.56% of the fungicides residues came from the approved ones, while 44.44% came from unused fungicides. Moreover, residues of one nematicide and parasitic pesticide were detected. The distribution of 42 pesticide residues were pesticides (18 compounds, 42.857%), herbicides (13 compounds, 30.952%), fungicides (9 compounds, 21.429%), nematode (one compound, 2.381%) and parasitic pesticide (one compound, 2.381%). 26 (61.905%) of the detected residues are still use, while 16 (38.095%) are unregistered, respectively.

4.2. Risk of dietary exposure to single and mixture of pesticide residues in fish

The risk quotient (RQ) is a measure of the potential health effects of consuming fish contaminated with pesticide residue and the health risk index (HI) of the pesticides mixture. We conducted a study to detect pesticide residues in fish samples collected from five locations in Lake Manzala (Legan, Elboghez, and Genka-El-Mataria) and to assess the dietary exposure risk to individual and combined pesticide residues. Fish from this lake are exposed to pesticide residues through their food, water, and aquatic environment. These residues may pose a threat to human health if they are consumed in large amounts or for a long time. The risk of consuming pesticide residues in food depends on several factors, such as the type and amount of fish consumed, the level and frequency of pesticide contamination, and the toxicity and interactions of the pesticides involved [51], [52], [53]. Some pesticides can have additive, synergistic, or antagonistic effects when they are present together, which means they can change each other's toxicity [54], [55]. Therefore, it is important to evaluate the risk of dietary exposure to multiple pesticide residues [56], [57]. The complexity, diversity, and impacts of pesticide mixtures on various species and outcomes make this a challenging task. Our results showed risk quotient (RQ) of pesticide residues and the health risk index (HI) of their mixture was below 1 (RQ or HI < 1) for eating fish from Lake Manzala, indicating that there was no health risk from individual pesticides or from the total amount of residues detected.

5. Conclusion

The water, sediment and fish samples from five locations in Lake Manzala were analyzed for pesticide residues. The results showed that 22 pesticides were detected in the water samples, 24 in the sediment samples and 20 in the fish samples. The number and level of pesticides varied by location, with Genka-El-Mataria, Bahr El-Baqur and Old sea outlet having the highest residues. The most common pesticides in all samples were Cadusafos, Cyprodinil, Thiram, aldicarb-sulfone-NH4+ and cyfluthrin-NH4. The analysis indicated that the lake is highly contaminated with pesticides from different sources. The environmental samples (water, sediment, and fish) from Lake Manzala contained 42 pesticide residues from various categories, including one endectocide for animal parasites. The pesticides included 18 insecticides, 13 herbicides, 9 fungicides, 1 nematicide, and 1 parasitic pesticide. Some of these pesticides were registered or approved for agricultural use, while others were unregistered or discontinued. The registered pesticides accounted for 60.71% of the total residues, while the unregistered ones accounted for 39.29%. The most common chemical groups were pyrethroids, dinitroaniline, and organophosphorus. We assessed the health risk of eating fish with pesticide residues from Lake Manzala. We found that the pesticide levels in the fish were below the ADI limit, and that the risk quotient (RQ) of each pesticide and health risk index (HI) of their combination was less than 1 (RQ or HI < 1). This means that the fish from this lake are safe to eat and do not pose any health risks from the pesticides.

6. Conflict of interests

The author(s) declare(s) that there is no conflict of interests regarding the publication of this article."

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