International Journal of Scientific Research and Management (IJSRM)
||Volume||12||Issue||10||Pages||7616-7630||2024||
Website: https://ijsrm.net ISSN: 2321-3418
DOI: 10.18535/ijsrm/v12i10.em08

Economic Impact of Heavy Metals Accumulation in Aquacultured Tilapia Fish in Egypt

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Abstract
Fish can accumulate heavy metals in their bodies from water through direct consumption or absorption through the gills, skin, and digestive system. Consequently, these metals can be transferred to humans through the consumption of contaminated fish, which may pose serious health risks. Therefore, human consumption of fish contaminated with toxic metals can cause various diseases such as liver cirrhosis and kidney failure. The study aimed to measure the potential health risks of exposure to heavy metals that exceeded the maximum limits, identify the most accumulated heavy metals in farmed fish, and assess the economic impact of the accumulation of some heavy metal elements in farmed fish in Kafr El-Sheikh and Fayoum governorates. This was done by collecting samples from several fish farms. One of the key findings of the study was the presence of multiple heavy metal elements, with arsenic and magnesium being prominent in the samples from both governorates, exceeding permissible limits in Kafr El-Sheikh. It was found that the non-compliant production in Kafr El-Sheikh averaged around 416,000 tons, valued at approximately 10 million EGP, indicating inefficient utilization of this production. In Fayoum, the non-compliant production for export specifications averaged around 14,000 tons, valued at approximately 348,000 EGP, also highlighting inefficient utilization of this production.

Keywords: Tilapia fish; Heavy metals; Risk assessment; Measuring the Economic Impact.

1. Introduction:

Fish are an important source of low-cost, high-nutritional food for all income groups in Egypt due to their content of protein, minerals, vitamins, and omega-3. They are also low in cholesterol and beneficial for human health, reducing the risk of heart diseases [1,2]. Egypt produces approximately 1.5 million tons of farmed fish, representing about 79% of the total fish production in Egypt [18] , which is estimated to be around 2 million tons. The average value of fish farming in 2022 was approximately 58.3 billion EGP, accounting for about 7.3% of the total value of agricultural production, which averaged around 802.9 billion EGP [19]. The average quantity of fish exports was about 28 thousand tons, with a value of approximately 708 million EGP, while the quantity of imports was about 298 thousand tons, with an import value of about 10.8 billion EGP [20]. Egypt ranks first among Arab countries in fish production, accounting for approximately 32% of the total fish production in Arab countries, which is around 6 million tons. Egypt's fish exports make up about 1.8% of the total fish exports of Arab countries, which is estimated at around 1.5 million tons, a relatively small proportion compared to production [3,4]. Nile tilapia, accounting for 65.15% of farmed freshwater fish in Egypt, is the most widely consumed fish in the country compared to other species [4].

A significant factor for this is that Egyptian law prohibits the use of Nile river fresh water for fish farming, instead encouraging the use of agricultural drainage water [5]. This drainage water is often contaminated with various chemical and biological hazards, such as heavy metals and pesticides [6,7]. Additionally, industrial wastewater, which is laden with harmful chemicals, can sometimes mix with agricultural drainage channels [8]. Due to human activities like the application of chemical fertilizers and pesticides in agriculture, these drainage channels tend to have elevated levels of heavy metals [9].
Fish can absorb heavy metals from their environment, either by direct ingestion or through their gills, skin, or digestive systems. As a result, these metals can accumulate in the fish's body and subsequently be passed on to humans when consumed, posing significant health risks [9]. Consumption of fish contaminated with toxic metals has been linked to various health issues, including liver cirrhosis [15] and kidney failure [16].

With regard to the previous facts, the present study aimed: 1) Measure the potential health risks of exposure to heavy metals that exceed the maximum limit. 2) Study the economics of farmed fish production in Egypt. 3) Identify the most accumulated heavy metals in farmed fish. 4) Measure the economic impact of the accumulation of some heavy metals in farmed fish.

2. Materials and Methods:

2.1. Site description of the studied aquacultures:

Ten aquaculture farms located in Kafr El-Sheikh and El-Faiyum governorates in Egypt (five farms from each governorate) were chosen for this study. These sites were selected due to their high production rates and the potential risk of pollution from elevated levels of toxic elements, as they rely on agricultural drainage water for fish farming.

2.2. Sampling time and handling:

Two sampling periods were selected for this study: autumn (September 2021) and spring (April 2022), to account for the expected significant variations in water quality between the summer and winter fish production cycles. The autumn and spring fish samples represent the summer and winter production cycles, respectively. The first phase of sampling, part of a preliminary survey, was conducted during the autumn of 2021 across the 10 selected farms. Based on the preliminary findings, the most heavily contaminated farms (four farms: two from each governorate) were chosen for the second phase of sampling in the spring of 2022 to continue the study.
Tilapia fish (Oreochromis niloticus), with an average body weight of 250-400 g, were collected directly from the farms at market times. The fish were stored in polystyrene boxes filled with ice and transported to the research laboratories in a refrigerated vehicle. Upon arrival, the fish samples were placed in polyethylene bags, grouped with replicates, labeled with codes, and then stored in a deep freezer at -20°C until analysis. Prior to analysis, the frozen samples were thawed at room temperature, eviscerated, washed, and the fish muscles were separated from the bones, minced, and then analyzed for heavy metal content.

2.3. Heavy metals analysis:

Heavy metals were extracted from the fish samples using the method described by Jiang et al. [18]. The concentrations of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) in all digested solutions were measured using Inductively Coupled Plasma–Optical Emission Spectrometry (ICP-OES). Additionally, total mercury (Hg) concentrations were analyzed using a Hydra-II AA Mercury Analyzer. Quality assurance and detection limits were established, demonstrating high recovery rates for the estimation of toxic metals using both the ICP-OES and Hydra-II AA Mercury Analyzer methods.

2.4. Human Risk Assessment:

Human risk assessment was estimated based on the guidelines of EPA [19–21]. Concentrations of heavy metals, data of surveyed questionnaire conducted on inhabitants of the studied region and some data of Integrated Risk Information System [22]. The daily intake (CDI) (mg/kg/day) from food ingestion was estimated using the following formula:

$$CDI = \frac{C.IR.ED.EF}{BW.AT}$$

Where C is the concentration of chemical expressed as mg/kg. IR is the ingestion rate (estimated for studied participants). ED is the average period (estimated). EF is the exposure frequency (meal/year). BW is the body weight (estimated). The AT is the averaging time (365 days/year; [23]).

$$\text{Risk}_{oral} = \text{CDI}_{oral} \times \text{SF}_{oral}$$

On the other hand, the non-carcinogenic risk will be evaluated based on the reference doses (RfDs). Target Hazard Quotient (THQ) of chemicals *via* ingestion route was calculated as follows:

$$THQ = \frac{CDI}{RfD}$$

Where, RfD is the reference dose of specified substances [22]. Total THQ (TTHQ) or hazard index (HI) is the sum of more than one hazard quotient for multiple substances.

2.5.Statistical analysis

The SPSS statistical program was used to calculate the averages for the study data and the Sign Test model was used for statistical analysis.

2.5.1. **The Sign Test:** The sign test is one of the easy and commonly used tests. It is named the sign test because it converts the data under analysis into positive and negative signs. The assumptions of the test are that the sample we are testing must be a random sample drawn from a continuously distributed population with an unknown median, and the data must be at least ordinal in measurement.

• Test hypothesis: The null hypothesis is based on the assumption that the median equals a certain value against any other alternative hypothesis.

1- H0 : me = me0 & H1 : me ≠ me0
2- H0 : me ≥ me0 & H1 : me < me0
3- H0 : me ≤ me0 & H1 : me > me0

Where: He: represents the median. me: represents the hypothesized median (a certain value).

Test Statistic:

$$p(k \leq x/n, p) = \sum_{k=0}^{n} \left(C\,{n \atop k}\right) p^k q^{n-k}$$

Where:

K: represents the number of negative signs in the study sample (under test).

x: number of signs under test.

n: number of observations under test.

Test procedures:

1. We assign a (+) sign for each observation that is greater than (me0) and a (-) sign for each observation that is less than (me0). We assign a value of zero for each observation that equals (me0) and ignore this observation.
2. In case of hypothesis (1), the test statistic tests the sign that occurs less frequently, whether it is positive or negative.
   - In case of hypothesis (2), the test statistic tests the number of positive signs.
   - In case of hypothesis (3), the test statistic tests the number of negative signs.
3. We extract the probability for the signs by applying the test statistic (binomial distribution) or from special tables for the binomial distribution.

Decision: If the calculated probability value is less than the chosen significance level, we reject the null hypothesis, and vice versa.

3. Results and Discussions:

3.1.Study of the Economics of Production and Export of Farmed Fish:

According to statistical data obtained from the Ministry of Agriculture and Land Reclamation (www.agri.gov.eg) during the average period of 2020-2022, it was found that the relative importance of fish farming during this period was about 79% of the total fish production in Egypt, with an average production of approximately 1.5 million tons out of a total fish production estimated at about 2 million tons. The average value of fish farming was approximately 58.3 billion pounds, accounting for about 7.3% of the total value of agricultural production, which averaged around 802.9 billion pounds, and representing about 76.2%

of the value of fish production, which was about 76.6 billion pounds. It was also found that the costs of fish production inputs in Egypt during the study period were about 34.3 billion pounds, with a relative importance of approximately 10.7% of the total costs of agricultural production inputs, which amounted to about 321.5 billion pounds, while the average net income for fish production was about 42.2 billion pounds. The average quantity of fish exports was about 28 thousand tons, with a value of about 708 million pounds, and the quantity of imports was about 298 thousand tons, with an import value of about 10.8 billion pounds (Table 1).

The relative importance of fish farming sectors in Egypt showed that private farms held the largest share at about 85.9% of the total fish farming, followed by floating cages at about 12.5%, then government farms, intensive farming, and rice fields at about 1.15%, 0.14%, and 0.36%, respectively (Table 2).

The estimated results of the relative importance of the geographical distribution of fish farming in Egypt showed that Kafr El-Sheikh Governorate held the largest share of farmed fish production during the average period of 2020-2022, with about 693 thousand tons representing about 44% of the total fish farming production. This was followed by the governorates of Port Said, Beheira, and Sharqia at about 19.5%, 12%, and 11.8%, respectively. Then came Damietta, Ismailia, Fayoum, and Alexandria at about 7.8%, 2.8%, 1.1%, and 0.8%, respectively (Table 3, Figure 1).

Table 1. The importance of the fish production, farmed Fish during the average period (2020-2022)

Year	Total fish production (1000 ton)			value of Agricultural Productio	Fish Production	Farmed Fish Value	Total Cost of Inputs	Cost of Fish Production	Total of Net Income	Fish Net Income	Export		Import	
	Natural Sources	Farmed Fish	%	L.E .million			L.E. million		L.E . million		Quantity (1000	Value (L.E.	Quantity (1000	Value (L.E.
2020	418	1,592	79.2	595,666	62,853	47,947	230,766	27,286	364,900	35,567	27	543	363	11,681
2021	426	1,576	78.7	742,517	67,540	51,017	297,797	30,013	444,719	37,526	27	779	323	9,745
2022	423	1,591	79.0	1,070,705	99,468	76,092	436,182	45,827	634,523	53,641	31	802	209	11,209
Average	422	1,586	79.0	802,963	76,620	58,352	321,582	34,375	481,381	42,245	28	708	298	10,878

Table 2. Farmed Fish (%)

	2020	2021	2022	Average
Governmental Farms	1.25	1.11	1.11	1.15
Compatriots Farms	85.6	86.0	86.0	85.9
Intensive Culture	0.15	0.13	0.15	0.14
In-Pond Raceway System (IPRS)	0.00	0.00	0.00	0.00
Floating Cages	12.6	12.4	12.3	12.5
Rice Fields	0.37	0.35	0.35	0.36

Table 3. Farmed Fish production in the governorates 2020-2022 (1000 ton)

Governorates	production
Kafr El-Sheikh	693.2
Port Sayed	309.6
Beheira	193.0
Sharqia	187.4
Damietta	123.9
Ismailia	44.1
Fayoum	17.5
Alexandria	12.8
*Other	4.5

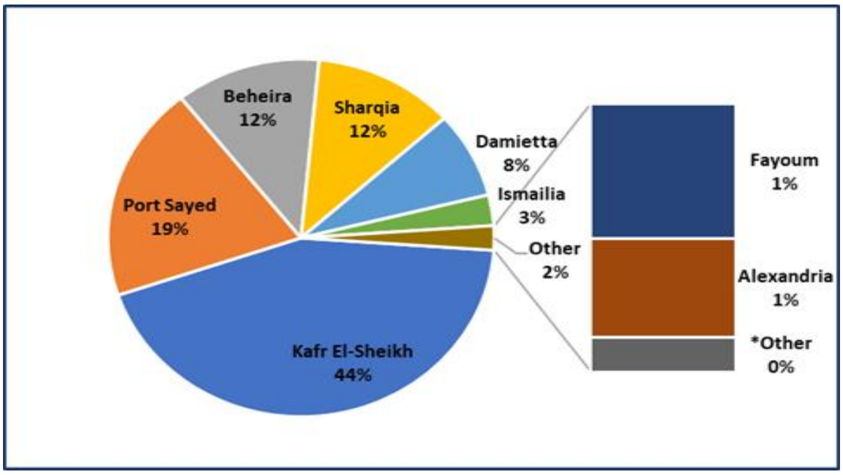

Figure 1

3.2.The Sign Test for Metal Concentration in a Sample of Farmed Fish:

The estimation was conducted according to the following hypotheses:

- Null hypothesis (H0): The average metal concentration in the fish is equal to or less than the permissible limit (M0).
- Alternative hypothesis (H1): The average metal concentration in the fish is greater than the permissible limit (M0).
  - H0: M = M0
  - H1: M > M0

In this case, the Sign Test was used to analyze the results of each province's samples to determine the concentration of each element, where the data was divided into two categories: above the permissible limit and below the permissible limit. Then, the Sign Test (2 Related Sample test) was used to test hypotheses regarding the comparison of the average samples from two farms in the first season with the average samples from the same two farms in the second season. This is evident from the estimation results in tables (4, 5, 6, 7).

3.2.1. Kafr El-Sheikh Governorate:

The metals most concentrated in the sample of farmed fish in Kafr El-Sheikh Governorate are arsenic and manganese (Mn, As) with concentrations ranging from (0.05: 2) and (2: 27) mg/Kg each, with an arithmetic mean of 1.39 and 13.9 mg/Kg, which is higher than the permissible limit of 0.5 mg/Kg, with a significance level of about 0.02 and 0.002. Therefore, the null hypothesis that the average metal concentration in the fish is equal to or less than the permissible limit is rejected.

The metals found in low concentrations in the sample of farmed fish are lead and zinc (Zn, Pb) with concentrations ranging from (0.05: 2.25) and (4.25: 44.75) mg/Kg each, with an arithmetic mean of 0.4 and

32.4 mg/Kg, which is lower than the permissible limit of 2 and 40 mg/Kg. It was found that Pb was present in 10% of the sample at a concentration higher than the permissible limit and Zn in 37% at a concentration higher than the permissible limit, with a significance level of about 0.004 and 0.72.

The metals that were concentrated in the sample but at levels lower than the permissible limit are copper and nickel (Ni, Cu), with an arithmetic mean of 1.65 and 0.5 mg/Kg, which is lower than the permissible limit of 20 and 10 mg/Kg, with a significance level of about 0.002 and 0.004. Therefore, the null hypothesis that the average metal concentration in the fish is equal to or less than the permissible limit is rejected. When comparing the farms with the highest heavy metal content in the first season with the same sample in the second season, the significance level indicated that there is no statistically significant difference between the two seasons.

3.2.2. Fayoum Governorate:

The metals most concentrated in the sample of farmed fish in Fayoum Governorate are arsenic, manganese, and zinc (Zn, Mn, As) with concentrations ranging from (0.5: 2), (0.05: 11.75), and (12: 55) mg/Kg each, with an arithmetic mean of 1.15, 3.5, and 39.7 mg/Kg, which is higher or nearly equal to the permissible limit of 0.5, 0.5, and 40 mg/Kg, with a significance level of about 0.004, 0.11, and 0.34.

The metals that were concentrated in the sample but at levels lower than the permissible limit are copper, nickel, and lead (Pb, Ni, Cu), with an arithmetic mean of 1.03, 0.12, and 0.05 mg/Kg, which is lower than the permissible limit of 20, 10, and 2 mg/Kg, with a significance level of about 0.002. Therefore, the null hypothesis that the average metal concentration in the fish is equal to or less than the permissible limit is rejected.

When comparing the farms with the highest heavy metal content in the first season with the same sample in the second season, the significance level indicated that there is no statistically significant difference between the two seasons.

Table 4. Descriptive Statistics

			N	Mean	Std. Deviation	Minimum	Maximum
Kafr El-Sheikh fish samples	As	1st season	10	1.39	.545	.05	2.00
	Cu	1st season	10	1.65	.699	.75	2.75
	Mn	1st season	10	13.93	10.976	2.00	27.00
	Ni	1st season	10	.50	.480	.05	1.00
	Pb	1st season	10	.41	.718	.05	2.25
	Zn	1st season	10	32.37	12.795	4.25	44.75
El Fayoum fish samples	As	1st season	10	1.15	.444	.50	2.00
	Cu	1st season	10	1.03	.478	.50	1.75
	Mn	1st season	10	3.53	3.877	.05	11.75
	Ni	1st season	10	.12	.221	.05	.75
	Pb	1st season	10	.05	.000	.05	.05
	Zn	1st season	10	39.7	15.53	12.00	55.00

Table 5. Binomial Test (1st season)

	Metals	MRL	Sign Test		N	Observed Prop	Exact Sig. (2-tailed)	Decision
Kafr El-Sheikh fish samples	As	0.5	sign	Group (-)	1	.10	.021	Reject the null hypothesis
				Group (+)	9	.90		
				Total	10	1.00		
	Cu	20	sign	Group (-)	10	1.00	.002	Reject the null hypothesis
				Group (+)	-	-		
				Total	10	1.00		
	Mn	0.5	sign	Group (-)	-	-	.002	Reject the null hypothesis
				Group (+)	10	1.00		
				Total	10	1.00		
	Ni	10	sign	Group (-)	10	1.00	.002	Reject the null hypothesis
				Group (+)	-	-		
				Total	10	1.00		
	Pb	2	sign	Group (-)	9	.90	.004	Reject the null hypothesis
				Group (+)	1	.10		
				Total	10	1.00		
	Zn	40	sign	Group (-)	5	0.63	.727	Retain the null hypothesis
				Group (+)	4	0.37		
				Total	9	1.00		
El Fayoum fish samples	As	0.5	sign	Group (-)	-	-	.004	Reject the null hypothesis
				Group (+)	9	1.00		
				Total	9	1.00		
	Cu	20	sign	Group (-)	10	1.00	.002	Reject the null hypothesis
				Group (+)	-	-		
				Total	10	1.00		
	Mn	0.5	sign	Group (-)	2	.20	.109	Retain the null hypothesis
				Group (+)	8	.80		
				Total	10	1.00		
	Ni	10	sign	Group (-)	10	1.00	.002	Reject the null

				Group (+)	-	-		hypothesis
				Total	10	1.00		
	Pb	2	sign	Group (-)	10	1.00	.002	Reject the null hypothesis
				Group (+)	-	-		
				Total	10	1.00		
	Zn	40	sign	Group (-)	3	.30	.344	Retain the null hypothesis
				Group (+)	7	.70		
				Total	10	1.00		

Table 6. Sign Test (Kafr El-Sheikh fish samples)

			N	Exact Sig. (2-tailed) [b]
As	2nd – 1st	Negative Differences[a]	4	.125
		Positive Differences[b]	0	
		Ties[c]	0	
		Total	4	
Cr	2nd – 1st	Negative Differences[a]	4	.125
		Positive Differences[b]	0	
		Ties[c]	0	
		Total	4	
Cu	2nd – 1st	Negative Differences[a]	3	.625
		Positive Differences[b]	1	
		Ties[c]	0	
		Total	4	
Fe	2nd – 1st	Negative Differences[a]	4	.125
		Positive Differences[b]	0	
		Ties[c]	0	
		Total	4	
Mn	2nd – 1st	Negative Differences[a]	4	.125
		Positive Differences[b]	0	
		Ties[c]	0	
		Total	4	
Ni	2nd – 1st	Negative Differences[a]	0	.125
		Positive Differences[b]	4	
		Ties[c]	0	
		Total	4	
Pb	2nd – 1st	Negative Differences[a]	3	.625
		Positive Differences[b]	1	
		Ties[c]	0	
		Total	4	
Zn	2nd – 1st	Negative Differences[a]	3	.625
		Positive Differences[b]	1	
		Ties[c]	0	
		Total	4	

a. x2 < x1; b. x2 > x1; c. x2 = x1	b. Binomial distribution used.

Table 7. Sign Test (El Fayoum fish samples)

			N	Exact Sig. (2-tailed) [b]
As	2nd – 1st	Negative Differences[a]	4	.125
		Positive Differences[b]	0	
		Ties[c]	0	
		Total	4	
Cr	2nd – 1st	Negative Differences[a]	4	.125
		Positive Differences[b]	0	
		Ties[c]	0	
		Total	4	
Cu	2nd – 1st	Negative Differences[a]	4	.125
		Positive Differences[b]	0	
		Ties[c]	0	
		Total	4	
Fe	2nd – 1st	Negative Differences[a]	4	.125
		Positive Differences[b]	0	
		Ties[c]	0	
		Total	4	
Mn	2nd – 1st	Negative Differences[a]	4	.125
		Positive Differences[b]	0	
		Ties[c]	0	
		Total	4	
Ni	2nd – 1st	Negative Differences[a]	1	.625
		Positive Differences[b]	3	
		Ties[c]	0	
		Total	4	
Pb	2nd – 1st	Negative Differences[a]	0	.125
		Positive Differences[b]	4	
		Ties[c]	0	
		Total	4	
Zn	2nd – 1st	Negative Differences[a]	4	.125
		Positive Differences[b]	0	
		Ties[c]	0	
		Total	4	
a. x2 < x1; b. x2 > x1; c. x2 = x1				b. Binomial distribution used.

3.3. *risk assessment for human exposure to HMs in fish*

The risk assessment data for exposure to the detected concentrations of heavy metals (HMs) in tilapia fish during autumn 2021 and spring 2022 are presented in Tables 4 and 5, respectively. The target hazard quotient (THQ) was calculated individually for each element, and the total THQ value, or hazard index (HI), was determined for each aquaculture farm by summing the THQ values for all HMs in the farm.

The results from season I (autumn 2021), shown in Table 4, revealed that arsenic (As) levels in fish samples from both Kafr El-Sheikh and El-Faiyum farms posed significant health risks. The THQ values for

As were well above 1, with Kafr El-Sheikh samples showing a THQ range of 3.15±0.5 and El-Faiyum samples a THQ range of 2.39±0.8. This indicates that human exposure to As exceeded the reference dose. In contrast, the THQ values for other heavy metals (Pb, Cu, Fe, Mn, Ni, Cr, and Zn) in both governorates were below 1, indicating the relative safety of these metals when considered individually.

The rank order of As THQ values for Kafr El-Sheikh farms was: farm 1 > farm 2 = farm 4 > farm 3 > farm 5. For El-Faiyum farms, the ranking was: farm 1 > farm 2 > farm 3 > farm 4 > farm 5. Additionally, the HI values, representing the combined THQs of all HMs, exceeded 1 for all farms. The HI rankings for Kafr El-Sheikh farms were: farm 4 > farm 2 > farm 1 > farm 5 > farm 3, while for El-Faiyum farms, the ranking was: farm 1 > farm 2 > farm 3 > farm 4 > farm 5.

Based on these results, farms 1 and 2 from Kafr El-Sheikh, as well as farms 1 and 2 from El-Faiyum, were selected for further heavy metals analysis during the second season. This decision was primarily driven by the elevated concentrations of As in these farms, given its high toxicity.

Farms 1 and 2 in Kafr El-Sheikh are located in the Al Haddadi area. Farm 1 uses the El-Naphlah agricultural drainage as its water source, which also serves as its outlet. In contrast, farm 2 is supplied by El-Mosraniah agricultural drainage. The absence of an outlet for farm 1 likely explains its higher level of HM pollution, as metals have accumulated in its water source (El-Naphlah drainage). In El-Faiyum, farms 1 and 2 use water from Qarun Lake, a closed reservoir that collects wastewater from agricultural areas and is heavily contaminated with HMs [26], which contributed to the high HM levels found in these farms [25].

The results from season II (spring 2022), shown in Table 5, demonstrated a notable reduction in HM concentrations in tilapia fish samples from both governorates compared to the first season. However, the same ranking trend of THQ values was observed: As > Cr > Fe. Additionally, all THQ and HI values for the farms in both governorates were below 1, indicating no significant health risks from exposure to the detected HMs in the tilapia fish during the second season.

3.4.Measuring the Economic Impact of Heavy Metal Accumulation on Farmed Fish in the Study Sample:

Based on the laboratory sample results collected from fish farms in the sample governorates of Kafr El-Sheikh and Fayoum, to measure the heavy metals, it was found that some study samples contained metals exceeding the maximum permissible limits, making them non-compliant with specifications due to their negative health effects on consumers. Therefore, the researcher assumed that samples exceeding the permissible limits of heavy metals represent unrealized profits or income if that production were directed for export, as detailed below:

3.4.1. Kafr El-Sheikh Governorate:

Table (8) shows that there are a total of 10 samples. Laboratory analysis results indicated that 9 samples contained the element (As) exceeding the permissible limit, representing about 90% of the total samples from the governorate. Ten samples contained the element (Mn) exceeding the permissible limit, representing 100% of the total samples from the governorate. One sample contained the element (Pb) exceeding the permissible limit, representing about 10% of the total samples from the governorate. Four samples contained the element (Zn) exceeding the permissible limit, representing about 40% of the total samples from the governorate. Based on the researcher's assumption, these percentages represent the production rate non-compliant with export specifications. The fish farming production in Kafr El-Sheikh was estimated to be about 693 thousand tons during the average period (2020-2022), with an average export price of approximately 24.8 thousand EGP/ton. The non-compliant production quantity was estimated to be about 416 thousand tons on average, representing unrealized income if directed for export without heavy metals. This income was estimated to average around 10 million EGP, indicating that this production was not efficiently utilized.

3.4.2. Fayoum Governorate:

The total samples from the governorate were 10. Laboratory analysis results indicated that 9 samples contained the element (As) exceeding the permissible limit, representing about 90% of the total samples from the governorate. Eight samples contained the element (Mn) exceeding the permissible limit, representing about 80% of the total samples from the governorate. Seven samples contained the element (Zn) exceeding the permissible limit, representing about 70% of the total samples from the governorate.

Based on the researcher's assumption, these percentages represent the production rate non-compliant with export specifications. The fish farming production in Fayoum was estimated to be about 17.5 thousand tons during the average period (2020-2022), with an average export price of approximately 24.8 thousand EGP/ton. The non-compliant production quantity was estimated to be about 14 thousand tons on average, representing unrealized income if directed for export without heavy metals. This income was estimated to average around 348 thousand EGP, indicating that this production was not efficiently utilized.

Table 8. The Economic Impact of Heavy Metal Accumulation on Farmed Fish in the Study Sample for the 2020/2021 Season

Governorate	Metals	the sample	Production (1000 ton)	Export price (1000 LE/ton)	Skipped samples		Off-spec production (1000 tons)	Unrealized income (1000 LE)
						%		
Kafr El-Sheikh	As	10	693.0	24.83	9	0.90	624	15,486
	Mn	10	693.0	24.83	10	1.00	693	17,207
	Pb	10	693.0	24.83	1	0.10	69	1,721
	Zn	10	693.0	24.83	4	0.40	277	6,883
							416	10324
El Fayoum	As	10	17.514	24.83	9	0.90	16	391
	Mn	10	17.514	24.83	8	0.80	14	348
	Pb	10	17.514	24.83	7	0.70	12	304
							14	348

4. Conclusion:

The Sign Test was used to analyze the results of each province's samples to determine the concentration of each element, The metals most concentrated in the sample of farmed fish in Kafr El-Sheikh Governorate are arsenic and manganese (Mn, As) with concentrations ranging from (0.05: 2) and (2: 27) mg/Kg each, with an arithmetic mean of 1.39 and 13.9 mg/Kg, which is higher than the permissible limit of 0.5 mg/Kg, with a significance level of about 0.02 and 0.002. Therefore, the null hypothesis that the average metal concentration in the fish is equal to or less than the permissible limit is rejected.

The metals most concentrated in the sample of farmed fish in Fayoum Governorate are arsenic, manganese, and zinc (Zn, Mn, As) with concentrations ranging from (0.5: 2), (0.05: 11.75), and (12: 55) mg/Kg each, with an arithmetic mean of 1.15, 3.5, and 39.7 mg/Kg, which is higher or nearly equal to the permissible limit of 0.5, 0.5, and 40 mg/Kg, with a significance level of about 0.004, 0.11, and 0.34.

Then, the Sign Test (2 Related Sample test) was used to test hypotheses regarding the comparison of the average samples from two farms in the first season with the average samples from the same two farms in the second season It was found from the significance level that there is no statistically significant difference between the test results in the two seasons in both governorates.

When measuring the economic impact of the accumulation of heavy metals on farmed fish in the study sample from Kafr El-Sheikh Governorate, it was found that the total samples included 10 samples. The laboratory analysis results showed that 9 samples contained arsenic (As) exceeding the permissible limit, representing about 90% of the total samples from the governorate. Additionally, 10 samples contained manganese (Mn) exceeding the permissible limit, representing about 100% of the total samples from the governorate. One sample contained lead (Pb) exceeding the permissible limit, representing about 10% of the total samples from the governorate. Four samples contained zinc (Zn) exceeding the permissible limit, representing about 40% of the total samples from the governorate. Based on the researcher's assumption, these percentages represent the production that does not meet export specifications. The production of farmed fish in Kafr El-Sheikh Governorate was estimated at approximately 693,000 tons during the average period (2020-2022), with an average export price estimated at around 24,800 EGP/ton. It was found that the non-compliant production quantity is approximately 416,000 tons. This production also represents potential income that could be achieved if it were directed for export without containing heavy metals, estimated at an average of around 10 million EGP, indicating that this production has not been efficiently utilized.

As for Fayoum Governorate, the total samples included 10 samples. The laboratory analysis results showed that 9 samples contained arsenic (As) exceeding the permissible limit, representing about 90% of the total samples from the governorate. Additionally, 8 samples contained manganese (Mn) exceeding the permissible limit, representing about 80% of the total samples from the governorate. Seven samples contained zinc (Zn) exceeding the permissible limit, representing about 70% of the total samples from the governorate. Based on the researcher's assumption, these percentages represent the production that does not meet export specifications. The production of farmed fish in Fayoum Governorate was estimated at approximately 17,500 tons during the average period (2020-2022), with an average export price estimated at around 24,800 EGP/ton. It was found that the non-compliant production quantity is approximately 14,000 tons. This production also represents potential income that could be achieved if it were directed for export without containing heavy metals, estimated at an average of around 348,000 EGP, indicating that this production has not been efficiently utilized.

5. Statements & Declarations

5.1. Funding:

This work was supported by the Science, Technology & Innovation Funding Authority (STDF) [grant numbers 41584, 2020]; PI. Prof. Mohamed Bedair M. Ahmed.

5.2. Competing Interests:

The authors affirm that they have no known financial or interpersonal conflicts that might have influenced the research presented in this study.

5.3. Data Availability:

Data will be made available from the corresponding author on request.

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