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# Potential health risk assessment for heavy metals in Tilapia fish of different spatiotemporal monitoring patterns in Kafr El-Shaikh and El-Faiyum Governorates of Egypt

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ABSTRACT

Heavy metal (HMs) levels were evaluated in aquacultured tilapia fish collected from two highly producing districts in Egypt (Kafr El-Sheikh and El-Faiyum Governorates) during two seasons (autumn 2021 and spring 2022). As well, health risk assessment of exposure to HMs in tilapia fish was studied. The results revealed that six HMs: As, Cu, Fe, Mn, Cr and Zn were predominant in fish samples of the first season (autumn 2021), while most of HMs were existed in samples of the second season. All samples of the two seasons were free of Hg. Notably, autumn season's fish samples showed higher concentrations of HMs than those of the spring season. As well, Kafr El-Sheikh farms were highly contaminated with HMs than those of El-Faiyum governorate. Risk assessment results indicated that the THQ values of As substantially exceeded 1 either for Kafr El-Shaikh samples (3.15 $\pm$ 0.5) or for El-Faiyum samples (2.39 $\pm$ 0.8) of autumn season. Meanwhile, THQ values for all HMs, in spring season 2021, were less than one whole. These results indicated a potential health risk arising from the exposure to HMs, As in particular, in fish samples of autumn season as compared to those of spring season. Therefore, there is a need for remedial applications, in such polluted aquacultures in autumn season, which are currently under investigation as an integral part of the research project that funded the current study.

## 1. Introduction

Fish meat is an important source of protein, polyunsaturated fatty acids, minerals, vitamins and omega-3, as well as low cholesterol source that provide a human health and reduce the incidence of heart disease [1,2]. Egypt is the top aquaculture producer in Africa, producing 63.2% of all fish produced in the continent and ranking seventh in the world in terms of production volume [3]. Nile tilapia fish, that counts 65.15% of freshwater farmed fish in Egypt, is the most popular and consumed fish between the Egyptian population as compared with other species [4].

The majority of fish farms in Egypt are found near the endpoints of saline plains and drainage canals. Because the Egyptian ministry of irrigation prohibits the use of River Nile fresh water in fish farms, and recommends the use of drainage water [5]. Agricultural drainage waters could be highly contaminated with a variety of chemical and biological hazards, including heavy metals and pesticides [6,7]. Agricultural drainage streams may also be mixed with industrial effluents that are highly contaminated with chemicals [8]. Due to anthropogenic activities like the use of chemical fertilizers and pesticides on agricultural land, these agricultural drainage streams may have greater concentrations of heavy metals [9].

Fish can accumulate heavy metals in their bodies from water through

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direct consumption of water or by uptake through the gills, skin and digestive tract [10]. In this respect, El-Batrawy et al. [9] noticed that the means levels of Pb, Cu, Mn, Zn, Fe and Ni in the muscles of Egyptian tilapia fish collected from Burullus Lake were 0.46, 0.39, 0.68, 4.70, 10.62 and 0.52 ppm, respectively. HMs are harmful for both fish and fish consumers as reported by Morshdy et al. [11]. They added that the exposure of fish to toxic metals such as cadmium (Cd) and Pb was altered the functionality of fish's antioxidant status. Also, Ibrahim et al. [12] reported that the increase of heavy metals in aquatic ecosystem lead to many of the histopathological impact such as degeneration, edema and splitting of fish muscle, as well as heavy metals can be affect the immune system of the fish and reduce the fish immunity to parasites [13]. Abdel-Mohsien and Mahmoud [14] revealed that the different organs of fish may be accumulated with heavy metals several times higher than their levels in the drainage water of the cultured media. Toxic metals can be transferred into human metabolism through consumption of contaminated fish that cause serious risks of the human health [9]. So, the human consumption of fish contaminated with toxic metals may induce numerous diseases such as the liver fibrosis [15] and kidney failure [16].

With regard to the previous facts, the present study aimed: 1) To evaluate the seasonal variation in the concentrations of heavy metals (Pb, Cd, As, Hg, Cu, Ni, Cr, Mn, Fe and Zn) in the edible muscle samples of aquacultured tilapia fish obtained from the most common two producing districts of Egypt namely Kafr El-Sheikh and El-Faiyum during two different seasons. 2) To study the potential risks of exposure to the determined concentrations of heavy metals in the collected samples during the studied seasons.

## 2. Materials and methods

### *2.1. Site description of the studied aquacultures*

Ten aquaculture farms in Kafr El-Sheikh and El-Faiyum governorates (5 farms from each governorate), Egypt were selected for the present investigation. The selected sites were known by their big production rate besides their potential pollution with elevated levels of toxic elements due to the used agricultural drainage water in production. The sampling sites were shown in Table 1 and Fig. 1.

### *2.2. Sampling time and handling*

Higher amounts of fertilizers and pesticides tend to be used in summer than in winter. So that, elevated concentrations of heavy metals could be expected in the agricultural drainage water of summer season than that of winter season. In this regard, two sampling dates (autumn: September 2021 and spring: April 2022) were selected due to the expected significant variation in water quality among the two different fish production cycles of summer and winter. Where, the autumn and spring fish samples represent the summer and winter production cycles, respectively. The first phase of sampling for the preliminary survey study was done in autumn season of 2021 on the studied 10 farms. Based on the results of the preliminary study, the highly contaminated farms (4 farms: 2 farms from each governorate) were only selected for the second phase of sampling (spring of 2022), to follow up the study.

Water samples of one liter each were collected, in clean glass bottles, from the selected sites. Bottles were labeled and transferred in a refrigerated car to the research laboratory. Water samples were filtered (through Whatman fiberglass filter, No. 3, England) to remove sand and debris and then stored at + 4 °C before analysis.

Tilapia fish (*Oreochromis niloticus*) samples, body weight average of 250–400 g, were collected directly from the farms, at marketing times, and kept in polystyrene boxes full of ice and then delivered to the research laboratories in a refrigerated car. Once receive the fish samples, they were kept in polyethylene bags, categorized into groups with replicates, coded and then stored in a deep freezer under − 20 °C until the time of analysis. Prior the analysis, the frozen samples were left for melting at room temperature, eviscerated, washed and then the fish muscles were separated from bones and minced before being subjected to the analysis of heavy metals.

**Table 1**
GPS locations for the studied aquaculture farms in Kafr El-Shaikh and El-Faiyum governorates.

| Governorate | Latitude | Longitude | Zone name |
|---|---|---|---|
| **Kafr El-Sheikh** | | | |
| Farm 1 | 31°22'24.18"N | 30°50'16.12"E | Al Haddadi WA Izabeha, Sidi Salem |
| Farm 2 | 31°22'57.16"N | 30°50'7.04"E | |
| Farm 3 | 31°22'39.32"N | 30°50'20.40"E | |
| Farm 4 | 31°24'35.02"N | 31° 5'12.48"E | Qetaa Mansour, El-Hamoul |
| Farm 5 | 31°24'30.87"N | 31° 5'13.85"E | |
| **El-Faiyum** | | | |
| Farm 1 | 29°26'4.15"N | 30°41'23.97"E | Qarun Lake Touristic Road, Ibsheway |
| Farm 2 | 29°26'37.84"N | 30°39'18.10"E | As Saaydah Al Qebleyah, Ibsheway |
| Farm 3 | 29°12'41.05"N | 30°26'9.16"E | Wadi El Rayan, Al Faiyum Governorate Desert |
| Farm 4 | 29°12'30.38"N | 30°26'12.55"E | |
| Farm 5 | 29°26'4.15"N | 30°41'23.97"E | |

### *2.3. Water characterization analysis*

Water quality was evaluated for the collected samples. Particularly, pH value, EC (μS $cm^{-1}$) and temperature (°C), were measured directly on-site using a Portable Multimeter. EC was modified, based on the standard temperature of measuring (25 °C), with a temperature correction coefficient of 0.0191 as recommended in Standard Methods for the Examination of Water and Wastewater [17]. Dissolved oxygen (DO) was measured with a DO Meter. For the determination of total phosphorus (TP), total nitrogen (TN), ammonia ($NH_4^+$), and chemical oxygen demand (COD), water samples were preserved by acidification to pH = 1–2, using sulfuric acid (0.1 N), and transported to the laboratory of National Research Centre (NRC) to determine TP, TN and COD using standard methods [17]. Samples for other parameters were kept in an icebox at 4 °C and transported to the laboratory of NRC for further analysis. Biological oxygen demand (BOD), and total suspended solids (TSS) were determined using standard methods [17].

### *2.4. Heavy metals analysis*

Heavy metals were extracted from water samples according to the standard method of APHA [17]. About 250 ml of collected water was filtered through Whatman filter paper (No. 1), and digested by 5 ml of concentrated nitric acid. The metals were extracted from fish samples following the method of Jiang et al. [18].

Concentrations of As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in all digested solutions were determined using Inductive Coupled Plasma–Optical Emission Spectrometry (ICP-OES) instrument. In addition, concentration of total Hg was determined using a Hydra-II AA Mercury Analyzer. Quality assurance and detection limits were determined with high recovery rate for toxic metals estimation using Plasma–Optical Emission Spectrometry (ICP-OES) and Hydra-II AA Mercury Analyzer.

### *2.5. Quality control and assurance*

The quality control program was carried out according to the following procedures: 1) Blank was run with each set of analysis. 2) Quantification of studied heavy metals was carried out using external standards with coefficient for calibration curves higher than 0.99. 3) The Calibration program for each parameter was verified on each working day by the measurement of one or more standards. 4) A random sample was run in triplicate. Laboratory control sample was analyzed with each series of samples (10 samples). 5) Q-chart was used and two values of


**Fig. 1.** Egypt map showing Kafr El-Sheikh and El-Faiyum governorates.

± 2 standard deviations are the lower and upper limits.

### 2.6. 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]).

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

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.

### 2.7. Statistical analysis

All data presented as mean ± SD were subjected to analysis of variance (ANOVA) and means were compared to significance by Student-Newman Keuls at the probability of 0.05 [24].

## 3. Results and discussion

### 3.1. Seasonal physicochemical characterization of aquaculture water

In the first season (autumn 2021), it was found that water pH is ranged from 7.3 to 9.04 in different fish farm. The Water salinity (EC), TDS, TSS were detected with higher values in aquaculture water collected from farm 1, farm 2 and farm 3 as shown in Table (2). Moreover, the levels COD and BOD show obvious variations in different Kafr

**Table 2**
Water physicochemical characterization of the aquaculture farms in Kafr El-Sheikh and El-Faiyum governorates (autumn 2021).

| Farm/Source | | | pH | EC (μS/cm | TDS (ppm) | TSS (ppm) | NO3 (ppm) | TON (ppm) | COD (ppm) | BOD (ppm) | $NH_4$ (ppm) | $PO_4$ (ppm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Kafr El-Sheikh Farms** | F1 | Inlet | 8.07 ± 0.01 | 9460 ± 89.81 | 5676 ± 73.48 | 152 ± 6.53 | 0.045 ± 0.002 | 6.72 ± 0.01 | 327 ± 1.63 | 188 ± 0.82 | 8.95 ± 0.02 | 1.33 ± 0.02 |
| | | Pond | 8.16 ± 0.08 | 11425 ± 7.07 | 7160 ± 381.84 | 138 ± 53.74 | 0.056 ± 0.022 | 20.28 ± 0.17 | 464 ± 203.65 | 262 ± 121.62 | 6.15 ± 0.78 | 1.76 ± 0.25 |
| | | Outlet | 7.98 ± 0.01 | 9680 ± 8.16 | 5892 ± 8.16 | 144 ± 0.82 | 0.043 ± 0.001 | 7.04 ± 0.01 | 323 ± 14.69 | 190 ± 4.08 | 8.4 ± 0.08 | 1.27 ± 0.02 |
| | F2 | Inlet | 8 ± 1.22 | 7024 ± 164.93 | 4214 ± 83.28 | 243 ± 9.79 | 0.012 ± 0.006 | 5.34 ± 0.01 | 13 ± 0.82 | 7.5 ± 0.16 | 10.64 ± 0.02 | 2.03 ± 0.02 |
| | | Pond | 8.26 ± 0.04 | 8130 ± 1315.22 | 5114.5 ± 1095.31 | 118 ± 14.14 | 0.08 ± 0.003 | 19.04 ± 0.08 | 250 ± 46.67 | 139 ± 24.04 | 4.34 ± 1.22 | 2.39 ± 0.03 |
| | | Outlet | 8.1 ± 0.08 | 6970 ± 73.48 | 4128 ± 80.08 | 252 ± 9.80 | 0.013 ± 0.003 | 5.1 ± 0.08 | 15 ± 1.63 | 6 ± 0.82 | 10.93 ± 0.10 | 2.08 ± 0.02 |
| | F3 | Inlet | 8 ± 0.82 | 7024 ± 83.28 | 4214 ± 84.92 | 243 ± 6.53 | 0.012 ± 0.002 | 5.34 ± 0.01 | 13 ± 0.82 | 7.5 ± 0.16 | 10.64 ± 0.03 | 2.03 ± 0.02 |
| | | Pond | 8.23 ± 0.08 | 7710 ± 608.11 | 4629 ± 369.11 | 59 ± 7.07 | 0.0575 ± 0.019 | 15.4 ± 0.08 | 118.5 ± 53.03 | 69 ± 28.28 | 3.655 ± 0.36 | 1.465 ± 0.60 |
| | | Outlet | 7.9 ± 0.08 | 7078 ± 83.28 | 4247 ± 79.20 | 234 ± 16.33 | 0.01 ± 0.004 | 5.6 ± 0.24 | 10 ± 1.63 | 9 ± 0.82 | 10.35 ± 0.29 | 1.97 ± 0.33 |
| | F4 | Inlet | 7.97 ± 0.18 | 11200 ± 0.41 | 630 ± 8.16 | 22 ± 0.82 | 0.03 ± 0.012 | 11.2 ± 0.16 | 19 ± 0.82 | 11 ± 0.82 | 10.1 ± 0.82 | 3.1 ± 0.33 |
| | | Pond | 7.99 ± 0.16 | 1920 ± 81.65 | 1047 ± 81.65 | 40 ± 4.08 | 0.081 ± 0.008 | 20.2 ± 0.41 | 29 ± 1.63 | 17 ± 1.63 | 6.72 ± 1.63 | 2.25 ± 0.09 |
| | | Outlet | 7.3 ± 0.16 | 3160 ± 77.57 | 1803 ± 81.64 | 42 ± 1.63 | 0.043 ± 0.008 | 7.1 ± 0.24 | 12 ± 2.45 | 9 ± 0.82 | 7.8 ± 0.82 | 2.07 ± 0.02 |
| | F5 | Inlet | 9.04 ± 0.09 | 1196 ± 86.55 | 678 ± 8.165 | 56 ± 2.45 | 0.042 ± 0.005 | 7.1 ± 0.33 | 17 ± 1.63 | 6 ± 0.82 | 5.08 ± 0.12 | 3.15 ± 0.08 |
| | | Pond | 8.92 ± 0.08 | 1205 ± 81.65 | 682 ± 9.80 | 54 ± 0.817 | 0.04 ± 0.008 | 7.3 ± 0.16 | 15 ± 2.04 | 8 ± 0.82 | 5.04 ± 0.08 | 3.15 ± 0.01 |
| | | Outlet | 7.4 ± 0.08 | 3128 ± 22.86 | 1790 ± 16.33 | 46 ± 1.63 | 0.05 ± 0.008 | 6.5 ± 0.16 | 16 ± 1.23 | 7 ± 0.82 | 7.9 ± 0.17 | 2.21 ± 0.07 |
| **El-Faiyum Farms** | F1 | Inlet | 7.91 ± 0.13 | 14.17 ± 3.63 | 9208 ± 2356.80 | 192.5 ± 151.85 | 0.21 ± 0.01 | 11.86 ± 0.65 | 857 ± 119.06 | 467 ± 58.09 | 5.28 ± 0.60 | 5.82 ± 1.19 |
| | | Pond | 7.73 ± 0.84 | 7.81 ± 5.39 | 5077 ± 3506.14 | 125.5 ± 7.72 | 0.09 ± 0.05 | 6.79 ± 0.09 | 239 ± 62.57 | 130 ± 34.09 | 4.43 ± 0.50 | 1.55 ± 0.17 |
| | | Outlet | 8.42 ± 0.09 | 12.16 ± 0.46 | 7901 ± 298.41 | 80.5 ± 14.55 | 0.178 ± 0.01 | 5.61 ± 3.88 | 186 ± 91.92 | 103 ± 51.17 | 4.9 ± 0.75 | 2.755 ± 2.20 |
| | F2 | Inlet | 7.59 ± 0.19 | 3.22 ± 0.30 | 2091 ± 197.11 | 37.5 ± 16.84 | 0.058 ± 0.01 | 4 ± 1.91 | 39 ± 8.85 | 22 ± 3.86 | 1.69 ± 0.09 | 3.30 ± 0.69 |
| | | Pond | 7.66 ± 0.69 | 3.73 ± 0.05 | 2425 ± 30.95 | 26 ± 12.75 | 0.1 ± 0.04 | 4.54 ± 1.35 | 108 ± 8.66 | 58 ± 2.94 | 3.06 ± 1.05 | 3.07 ± 0.56 |
| | | Outlet | 7.95 ± 0.38 | 3.50 ± 0.29 | 2277 ± 191.52 | 74 ± 3.27 | 0.188 ± 0.16 | 3.9 ± 0.64 | 85 ± 24.82 | 47 ± 13.92 | 2.58 ± 0.39 | 0.41 ± 0.02 |
| | F3 | Inlet | 8.19 ± 0.02 | 3.06 ± 0.04 | 1986 ± 23.81 | 98 ± 91.26 | 0.165 ± 0.12 | 3.93 ± 0.64 | 40 ± 4.79 | 22 ± 2.38 | 2.67 ± 0.26 | 5.30 ± 5.35 |
| | | Pond | 7.92 ± 0.43 | 3.87 ± 0.22 | 2518 ± 142.17 | 125 ± 78.87 | 0.115 ± 0.07 | 5.66 ± 3.86 | 241 ± 35.60 | 131 ± 19.97 | 2.20 ± 0.53 | 3.39 ± 1.20 |
| | | Outlet | 7.66 ± 0.40 | 4.34 ± 0.44 | 2818 ± 287.34 | 12 ± 7.85 | 0.31 ± 0.07 | 10.22 ± 1.49 | 97 ± 60.39 | 54 ± 34.42 | 3.15 ± 1.68 | 0.78 ± 0.51 |
| | F4 | Inlet | 7.9 ± 0.15 | 8.79 ± 4.37 | 5714 ± 2841.12 | 22 ± 3.65 | 0.37 ± 0.30 | 5.74 ± 2.47 | 30 ± 4.80 | 17 ± 2.38 | 1.25 ± 0.13 | 0.58 ± 0.27 |
| | | Pond | 8.02 ± 0.61 | 3.51 ± 0.21 | 2280 ± 138.19 | 26.25 ± 23.98 | 0.22 ± 0.01 | 5.16 ± 2.13 | 131 ± 1.15 | 74 ± 1.15 | 2.31 ± 0.07 | 1.06 ± 0.59 |
| | | Outlet | 7.97 ± 0.18 | 4.02 ± 0.10 | 2610 ± 66.25 | 51 ± 23.12 | 0.09 ± 0.04 | 5.6 ± 2.56 | 81 ± 21.75 | 45 ± 11.30 | 3.4 ± 0.48 | 1.45 ± 0.82 |
| | F5 | Inlet | 7.78 ± 0.46 | 9.16 ± 6.71 | 5953 ± 4362.58 | 22 ± 3.76 | 0.115 ± 0.01 | 4.05 ± 0.58 | 150 ± 133.71 | 83 ± 74.23 | 2.47 ± 1.06 | 0.54 ± 0.30 |
| | | Pond | 7.83 ± 0.32 | 9.81 ± 6.56 | 6374 ± 4263.20 | 126.5 ± 44.55 | 0.155 ± 0.03 | 8 ± 2.71 | 129 ± 13.22 | 71 ± 5.68 | 2.05 ± 0.35 | 0.76 ± 0.04 |
| | | Outlet | 7.84 ± 0.33 | 9.52 ± 7.01 | 6188 ± 4555.98 | 154.5 ± 87.20 | 0.18 ± 0.13 | 5 ± 0.50 | 52 ± 29.56 | 28 ± 15.02 | 1.82 ± 1.35 | 0.40 ± 0.15 |
| Detection limit | | | - | - | 5 | 5 | 0.01 | 3 | 5 | 5 | 0.5 | 0.22 |

Total dissolved solids (TDS), total suspended solids (TSS), total organic nitrogen (TON), chemical oxygen demand (COD), biological oxygen demand (BOD), and ammonia (NH4

El-Sheikh farms. Meanwhile TON and ammonia were detected with high values in all farms. Also, concentrations of phosphate were 1.47–3.15 mg $L^{-1}$. As the pond water quality showed the highest contamination level with different pollution indicators in Farms 1–3. This could be due to the absence of circulation system and mechanical aeration in the studied farms. Farms 1 and 2 of Kafr El-Sheikh are located in Al Haddadi zone. El-Naphlah agricultural drainage, which serves as the water supply for Farm 1, is also regarded as outlet of Farm 1. However, the source of water supply to Farm 2 is El-Mosraniah agricultural drainage. The absence of outlet for Farm 1 may help to explain why Farm 1 has the highest concentrations of HMs, of which had been accumulated in the water supply source (El-Naphlah drainage). As well, TSS level in outlets of some farms has higher values than that of inlet, because of absence of any wastewater treatment. Water quality in Farm 4 and Farm 5 showed lower values for pollution indicators.

In El-Faiyom governorate, aquaculture water is slight alkaline with

7.59 – 8.42 pH value. Water salinity (EC), TDS, TSS and TON, COD, BOD, and $NH_4$ were in highest values in aquaculture water collected from all farms except for farm 2 as shown in Table (2). The concentrations of phosphate were 0.40–5.82 mg $L^{-1}$. On the other hand, the water supply of farms 1 and 2, of El-Faiyum governorate which showed the highest values, is Qarun Lake which is a closed reservoir for the wastewater discharged from the agricultural lands in El-Faiyum governorate [25] and it is highly contaminated by HMs [26].

In the second season (spring 2022), the water quality of inlet and outlet of aquaculture and ponds was investigated in Kafr El-Sheikh El-Faiyum governorates (Table 3). The obtained results revealed that there was no detection for ammonia in all aquacultures inlet and outlets. Also, measured values of pH indicated a slight alkaline nature of water in all studied farms. Regarding to salinity of fish aquaculture, TDS values indicated that water salinity ranged from 1.56% to 9.66%. Total suspended solids (TSS) values are ranged from 26 to 126.5 ppm. The results of nutrients (nitrate, TON, phosphate) indicated high levels of phosphate in some sites. The COD and BOD have fluctuated values in all sites with level ranges of 108 – 241 ppm and 58 – 131 ppm, respectively. The obtained results showed a significant variation in levels of salinity, ammonia, TON nitrate and phosphorus. Meanwhile COD and BOD showed a high significant difference between season I (autumn) and season II (spring).

The high levels of COD, BOD and TON are owed to the existence of organic pollution, which can be comprehended from the detected unionized toxic ammonia, and total phosphorus. Based on the current work, it was found that water quality indicators were higher than those of the permissible limits of River Nile water [27]. Moreover, free ammonia is highly toxic material to aquatic organisms which has delayed fish growing [28]. As well, TSS level in outlets of some farms has higher values than that of inlet, because of the absence of any wastewater treatment. Water quality in Farm 4 and Farm 5 showed lower values for pollution indicators. Conclusively, post-treatment stage for outlet of fish aquaculture will be recommended for reduction of pollution levels and attaining zero-liquid discharge concept.

### 3.2. Seasonal evaluation for HMs levels in fish

The results showed that Hg element was not detected in all farms of both governorates through the two studied seasons (Tables 4 and 5). The results of the first phase (autumn 2021) revealed that As, Cu, Fe, Mn, Cr and Zn were positively detected in all samples of Kafr El-Sheikh aquacultures (Table 4). No significant differences were obtained in As levels (1.25–1.68 mg/kg dry w) and Cu levels did not exceed 2.38 mg/kg dry w. Iron exhibited the greatest level 375.3 mg/kg dry w in samples of farm 5, followed by 373.3 mg/kg dry w in farm 4 and 171.3 mg/kg dry w in farm 2, while the least level (60.0 mg/kg dry w) was detected in farm 1. Manganese exhibited the greatest value in farms 5, 4 and 2 being 26.75, 26.00 and 8.50 (mg/kg), respectively. The highest level of Cr (2.26 mg/kg dry w) was detected in farm 4, while other levels ranged from 0.88 to 2.25 mg/kg dry w. Zinc (Zn) values ranged from 22.13 to 42.75 mg/kg dry w. Lead and Ni were the least abundant elements in autumn 2021. Lead was positively detected only in farms 2 and 3 with values: 1.00 and 1.38 mg/kg dry w, respectively. As well, low detected levels were noticed for Ni, which ranged from 0.88 to 1.00 mg/kg dry w in farms 3, 4 and 5, but not detected in farms 1 and 2.

According to FAO [29] and EOS [30], 100% of the detected concentrations of As and Mn in Kafr El-Sheikh farms were above the MRLs in fish which assigned as 0.5 ppm for both elements. As well, 40% of Zn concentrations exceeded the MRL (40 ppm), whereas, all the detected levels of Cd, Pb, Cu and Ni were lower than the MRLs (0.5, 2.0, 20, and 10 ppm, respectively) (Fig. 2a).

Regarding El-Faiyum governorate, most detected metals were lower than those detected in Kafr El-Sheikh farms during autumn 2021 (Table 4). Arsenic concentrations located in the range of 0.75–1.5 mg/kg dry w, while Cu levels ranged from 0.50 to 1.50 mg/kg dry w. Iron showed the descending order of contamination as follows; farm 1, 3 and 4 being 160, 95 and 60 (mg/kg), respectively. Manganese content ranged from 1.00 to 9.25 mg/kg dry w, but Cr levels located in the range of 1–2 mg/kg dry w. The least level of Zn was found in farm 5 (13.50 mg/kg dry w), while other values fluctuated between 36.25 and 51.25 mg/kg dry w. Lead and Ni were the least abundant elements in El-

**Table 3**
Water physicochemical characterization of the aquaculture farms of Kafr El-Sheikh and El-Faiyum governorates (spring 2022).

| Farm/Source | | | pH | EC (μs/cm) | TDS ppm | TSS ppm | NO3 ppm | TON ppm | COD ppm | BOD ppm | $NH_4$ (ppm) | PO4 ppm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Kafr El-Sheikh Farms** | F1 | Inlet | 6.62 ± 0.02 | 8795 ± 276 | 5806.75 ± 156 | 102.5 ± 18 | 1.93 ± 0.26 | 4.98 ± 0.61 | 151.75 ± 21.28 | 81.75 ± 12.04 | < 0.5 | 0.94 ± 0.51 |
| | | Pond | 8.55 ± 0.08 | 9825 ± 114 | 6451.75 ± 89 | 86.25 ± 33 | 2.76 ± 0.09 | 2.78 ± 1.29 | 169.75 ± 27.63 | 98.50 ± 12.12 | < 0.5 | 0.81 ± 0.11 |
| | | Outlet | 6.92 ± 0.11 | 11985 ± 1577 | 7889.5 ± 1065 | 83.25 ± 63 | 2.07 ± 0.52 | 4.46 ± 0.63 | 142.75 ± 21.65 | 78.50 ± 6.46 | < 0.5 | 8.24 ± 1.06 |
| | F2 | Inlet | 8.14 ± 0.01 | 14550 ± 71 | 9563 ± 103 | 85 ± 4.24 | 1.08 ± 0.04 | 4.45 ± 0.04 | 158.50 ± 17.67 | 97.50 ± 6.36 | < 0.5 | 6.51 ± 0.01 |
| | | Pond | 8.49 ± 0.05 | 11427.5 ± 806 | 7503.25 ± 530 | 81 ± 56.6 | 1.56 ± 0.11 | 3.82 ± 1.41 | 186.75 ± 11.84 | 103.50 ± 1.91 | < 0.5 | 1.61 ± 0.67 |
| | | Outlet | 8.13 ± 0.01 | 14725 ± 35 | 9661.5 ± 104 | 74 ± 2.83 | 2.10 ± 0.57 | 3.35 ± 0.01 | 185.50 ± 21.92 | 103.00 ± 7.07 | < 0.5 | 7.02 ± 0.01 |
| **El-Faiyum Farms** | F1 | Inlet | 8.07 ± 0.63 | 11002.5 ± 604 | 7208.5 ± 417 | 142.5 ± 16.11 | 1.93 ± 0.64 | 3.27 ± 0.72 | 130.50 ± 48.23 | 76.00 ± 25.26 | < 0.5 | 15.44 ± 4.17 |
| | | Pond | 7.92 ± 0.20 | 9135 ± 1688 | 6006.5 ± 1108 | 185 ± 72.19 | 1.80 ± 0.59 | 4.19 ± 1.02 | 106.75 ± 54.919 | 62.75 ± 28.08 | < 0.5 | 12.01 ± 0.01 |
| | | Outlet | 7.69 ± 0.05 | 2427.5 ± 21 | 1593.5 ± 14 | 31.5 ± 3.42 | 1.09 ± 0.38 | 6.43 ± 3.56 | 91.50 ± 6.35 | 53.75 ± 3.30 | < 0.5 | 8.30 ± 0.65 |
| | F2 | Inlet | 7.71 ± 0.14 | 9395 ± 2258 | 6189.75 ± 1491 | 29 ± 7.75 | 0.59 ± 0.095 | 3.07 ± 0.97 | 82.00 ± 19.98 | 49.25 ± 10.21 | < 0.5 | 2.77 ± 2.23 |
| | | Pond | 7.88 ± 0.02 | 10012.5 ± 234 | 6576.25 ± 134.16 | 34 ± 8.16 | 1.17 ± 0.03 | 3.57 ± 1.01 | 79.00 ± 11.75 | 47.50 ± 5.26 | < 0.5 | 4.39 ± 3.63 |
| | | Outlet | 8.10 ± 0.02 | 9795 ± 168 | 6442.25 ± 110 | 29.5 ± 11.36 | 0.91 ± 0.47 | 2.24 ± 0.68 | 74.25 ± 10.84 | 47.25 ± 6.13 | < 0.5 | 7.93 ± 0.11 |
| Detection limit | | | - | - | 5 | 5 | 0.01 | 3 | 5 | 5 | 0.5 | 0.22 |

Total dissolved solids (TDS), total suspended solids (TSS), total organic nitrogen (TON), chemical oxygen demand (COD), biological oxygen demand (BOD), and ammonia (NH4 +)

**Table 4**
Levels and risk assessment of heavy metals (mg/kg) in tilapia fish samples from Kafr El-Sheikh and El-Faiyum governorates (autumn 2021).

| Farms | | | As | Cd | Pb | Cu | Fe | Mn | Ni | Cr | Zn | HI = Σ THQ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Kafr El-Sheikh Farms** | **1** | Conc. | 1.68 ± 0.09 | <DL | <DL | 2.29 ± 0.43 | 60.0 ± 5.77 | 2.25 ± 0.29 | <DL | 0.88 ± 0.15 | 25.63 ± 5.05 | **3.90** |
| | | THQ | 3.56 | - | - | 0.036 | 0.054 | 0.010 | - | 0.186 | 0.054 | |
| | **2** | Conc. | 1.63 ± 0.43 | <DL | 1.00 ± 0.0 | 2.38 ± 0.14 | 171.3 ± 14 | 8.50 ± 1.73 | <DL | 1.88 ± 0.14 | 22.13 ± 2.06 | **4.15** |
| | | THQ | 3.45 | - | - | 0.039 | 0.156 | 0.039 | - | 0.398 | 0.047 | |
| | **3** | Conc. | 1.50 ± 0.0 | <DL | 1.38 ± 1.0 | 1.00 ± 0.0 | 70.0 ± 17.32 | 6.13 ± 1.59 | 1.00 ± 0.0 | 1.38 ± 0.14 | 28.75 ± 4.33 | **3.67** |
| | | THQ | 3.18 | - | - | 0.016 | 0.064 | 0.028 | 0.032 | 0.292 | 0.061 | |
| | **4** | Conc. | 1.63 ± 0.14 | <DL | <DL | 1.50 ± 0.29 | 373.3 ± 85.7 | 26.00 ± 1.15 | 0.88 ± 0.14 | 2.26 ± 0.39 | 42.63 ± 2.45 | **4.53** |
| | | THQ | 3.45 | - | - | 0.024 | 0.339 | 0.118 | 0.028 | 0.477 | 0.090 | |
| | **5** | Conc. | 1.25 ± 0.29 | <DL | <DL | 1.00 ± 0.29 | 375.3 ± 74.8 | 26.75 ± 0.29 | 1.00 ± 0.0 | 2.25 ± 0.28 | 42.75 ± 2.02 | **3.73** |
| | | THQ | 2.65 | - | - | 0.016 | 0.341 | 0.121 | 0.032 | 0.476 | 0.091 | |
| **El-Faiyum Farms** | **1** | Conc. | 1.50 ± 0.58 | <DL | <DL | 1.13 ± 0.43 | 160.0 ± 8.7 | 5.75 ± 1.44 | <DL | 1.38 ± 0.43 | 50.0 ± 2.89 | **3.77** |
| | | THQ | 3.18 | - | - | 0.018 | 0.145 | 0.026 | - | 0.292 | 0.106 | |
| | **2** | Conc. | 1.38 ± 0.14 | <DL | <DL | 1.50 ± 0.29 | 47.5 ± 5.77 | 9.25 ± 2.89 | 0.75 ± 00 | 2.00 ± 0.58 | 51.25 ± 4.33 | **3.59** |
| | | THQ | 2.92 | - | - | 0.024 | 0.043 | 0.042 | 0.024 | 0.424 | 0.109 | |
| | **3** | Conc. | 1.13 ± 0.43 | <DL | <DL | 1.13 ± 0.34 | 95.0 ± 57.74 | 1.63 ± 0.14 | <DL | 1.00 ± 0.00 | 47.50 ± 5.77 | **2.82** |
| | | THQ | 2.39 | - | - | 0.018 | 0.086 | 0.007 | - | 0.212 | 0.101 | |
| | **4** | Conc. | 1.00 ± 0.29 | <DL | <DL | 0.88 ± 0.42 | 60.0 ± 0.00 | 1.00 ± 0.00 | <DL | 1.13 ± 0.14 | 36.25 ± 7.22 | **2.51** |
| | | THQ | 2.12 | - | - | 0.014 | 0.055 | 0.005 | - | 0.239 | 0.077 | |
| | **5** | Conc. | 0.75 ± 0.29 | <DL | <DL | 0.50 ± 0.00 | 27.5 ± 2.89 | <DL | <DL | <DL | 13.50 ± 1.73 | **1.65** |
| | | THQ | 1.59 | - | - | 0.008 | 0.025 | - | - | - | 0.029 | |
| Detection limit (mg/kg) | | | < 0.005 | < 0.0025 | < 0.01 | < 0.01 | < 0.05 | < 0.05 | < 0.01 | < 0.01 | < 0.05 | |

Hg in fish samples were below detection limits of 0.001 (mg/kg). THQ: Total hazard quotient. HI: Hazard index.

**Table 5**
Levels and risk assessment of toxic metals (mg/kg) in tilapia fish samples from Kafr El-Sheikh and El-Faiyum governorates (spring 2022).

| Farms | | | As | Cd | Pb | Cu | Fe | Mn | Ni | Cr | Zn | HI = Σ THQ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Kafr El-Sheikh Farms** | **1** | Conc. | 0.16 ± 0.02 | 0.01 ± 0.0 | 0.06 ± 0.05 | 0.98 ± 0.3 | 15.67 ± 7.8 | 3.46 ± 3.4 | 0.25 ± 0.06 | 0.98 ± 0.32 | 6.90 ± 0.29 | **0.443** |
| | | THQ | 0.339 | 0.006 | - | 0.016 | 0.014 | 0.016 | 0.008 | 0.208 | 0.015 | |
| | **2** | Conc. | 0.13 ± 0.03 | 0.01 ± 0.0 | 0.06 ± 0.05 | 0.78 ± 0.1 | 13.22 ± 2.2 | 0.58 ± 0.01 | 0.15 ± 0.05 | 0.78 ± 0.10 | 6.34 ± 0.26 | **0.311** |
| | | THQ | 0.275 | 0.006 | - | 0.012 | 0.012 | 0.003 | 0.005 | 0.165 | 0.013 | |
| **El-Faiyum Farms** | **1** | Conc. | 0.10 ± 0.01 | 0.02 ± 0.0 | 0.10 ± 0.01 | 0.48 ± 0.09 | 17.64 ± 4.8 | 0.48 ± 0.09 | 0.10 ± 0.01 | 0.48 ± 0.09 | 5.85 ± 0.42 | **0.251** |
| | | THQ | 0.201 | 0.007 | - | 0.008 | 0.016 | 0.002 | 0.003 | 0.002 | 0.012 | |
| | **2** | Conc. | 0.10 ± 0.01 | 0.01 ± 0.0 | 0.10 ± 0.00 | 0.47 ± 0.00 | 12.77 ± 7.4 | 0.44 ± 0.05 | 0.19 ± 0.00 | 0.48 ± 0.00 | 5.12 ± 0.02 | **0.257** |
| | | THQ | 0.201 | 0.006 | - | 0.008 | 0.012 | 0.002 | 0.006 | 0.012 | 0.011 | |
| Detection limit (mg/kg) | | | < 0.005 | < 0.0025 | < 0.01 | < 0.01 | < 0.05 | < 0.05 | < 0.01 | < 0.01 | < 0.05 | |

Hg in fish samples were below detection limits of 0.001 (mg/kg). THQ: Total hazard quotient. HI: Hazard index.

Faiyum farms during autumn 2021. Particularly, Ni was non-detectable in all samples, except farm 2 (0.75 mg/kg dry w), however Pb was not detected in all samples. The determined values of Cd, Pb, Cu and Ni in fish samples of El-Faiyum located in the safe limits as compared to their MRLs in fish (Fig. 2b). On the other hand, 100%, 80% and 60% of the determined concentrations of As, Mn, and Zn were above MRLs (Fig. 2b).

The highly contaminated farms with toxic metals (As in particular) were selected for the next season of HMs monitoring (spring 2022) and other complementary studies related to the mitigation treatments. The selected farms from both governorates were farms No. 1 and 2.

Concerning the second season of HMs monitoring (spring 2022), obtained results of Table 5 showed that, heavy metals in farm 1 of Kafr El-Sheikh aquacultures displayed the following concentrations: 0.16, 0.01, 0.06, 0.98, 15.67, 3.46, 0.25, 0.98, and 6.90 mg/kg dry w for AS, Cd, Pb, Cu, Fe, Mn, Ni, Cr and Zn, respectively. While farm 2 displayed the following concentrations: 0.13, 0.01, 0.06, 0.78, 13.22, 0.58, 0.15, 0.78 and 6.34 mg/kg dry w for the above metals. With regard to El-Faiyum governorate, farm 1 displayed the order: 0.1. 0.02, 0.1, 0.48, 17.6, 0.48, 0.10, 0.48 and 5.85 mg/kg dry w for aforementioned metals, while farm 2 displayed the values: 0.10, 0.01, 0.10, 0.47, 12.77, 0.44, 0.19, 0.48 and 5.12 mg/kg dry w at the same manner. Generally, results of the second season (spring 2022) which represented the winter production cycle of Tilapia fish exhibited lower concentrations of HMs than those of the first season (autumn 2021) which represented the summer production cycle of Tilapia fish. Notably, except for Mn in Kafr El-Sheikh

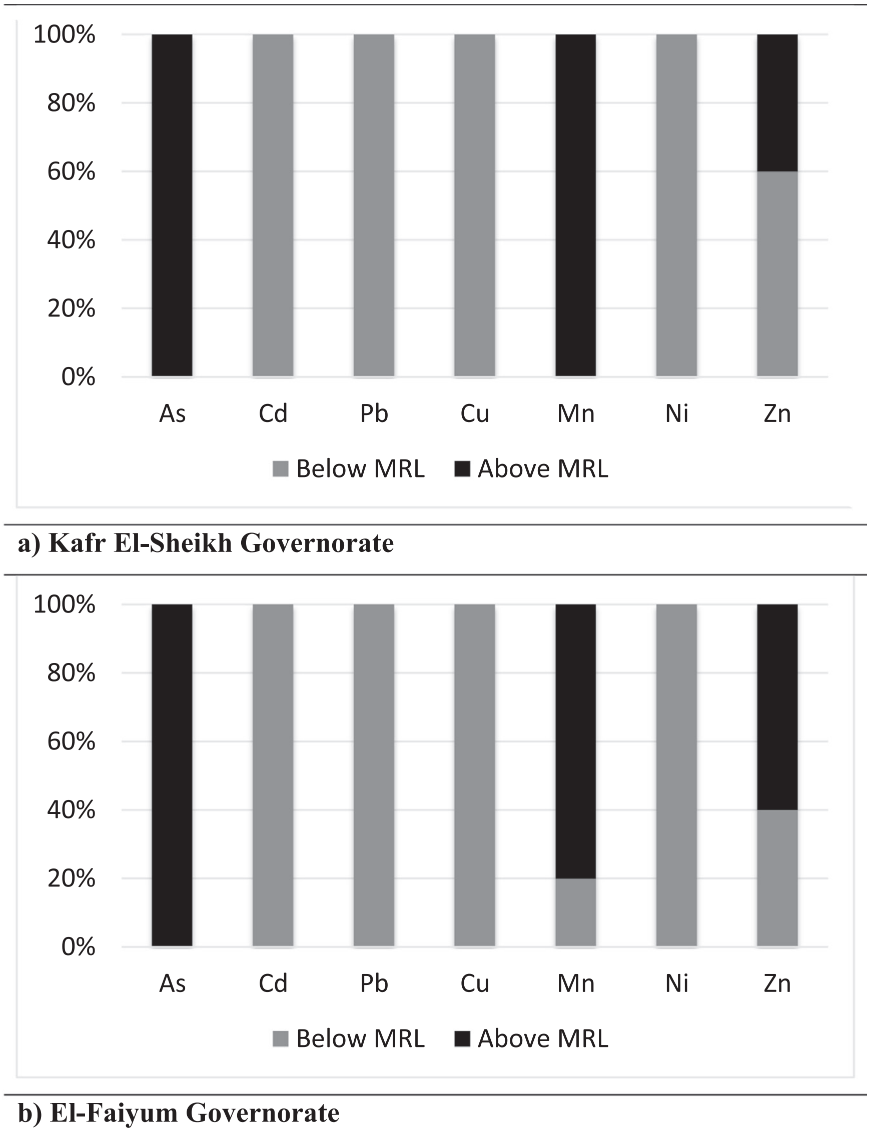


**Fig. 2.** Percentages of HMs' concentration compared to their MRLs (autumn 2021). MRLs values (ppm) for As, Cd, Pb, Cu, Ni, Zn and Mn in fish muscles are 0.5, 0.5, 2.0, 20, 10, 40 (EOS [30]) and 0.5 (FAO [29]).

aquacultures, the obtained concentrations of all elements, in both governorates at 2021, were lower than their MRLs (Fig. 3a and b).

It's worthy to mention that, in Egypt, cultivation of economic crops of the summer season such as cotton, rice, maize and linen required the extensive usage of fertilizers and pesticides. However, winter season crops such as legumes (all beans' varieties and alfalfa) do not require application of fertilizers. So that, higher amounts of fertilizers and pesticides tends to be used in summer than in winter. In this concern, several studies reported that the usage of fertilizers and pesticides in agricultural practices is associated with the contamination of agro-systems with heavy metals. According to Atafar et al. [31], the long-term application of fertilizer and manure raised the levels of As, Pb, and Cd in the soil and farmed plants. Furthermore, Salem et al. [32] reported that adding phosphate and urea fertilizers raised the concentrations of metals (Pb, Cr, Cd, Cu, Mn, Zn, and Ni) in agricultural soil. They also added that the usage of herbicide in agriculture may also help in increasing Cu level in the plants. Additionally, Bempah et al. [33] suggested that the usage of metal-based insecticides or fertilizer during agricultural activities may be the cause of the metals contamination. Moreover, the elevated concentrations of HMs in samples of autumn season (end of summer production cycle), as compared to other seasons, could be due to the increase of evaporation rate during summer, leading to increased concentration of HMs in the water, as well as the increased activity of fishermen during the summer leads to an increase in pollution from fishing boats waste as confirmed by Bahnasawy et al. [34] and Shaker et al. [35].

These above-mentioned facts clarify the potential reasons behind the elevated levels of HMs in autumn samples of drainage water than that of spring samples, which may, consequently, explain the higher content of accumulated HMs in fish muscles of autumn 2021 than that of spring 2022. These findings were in line with those made by Abd-El-Khalek et al., Farouk et al., Girgis et al., and Yacoub and Gad [36–39] who discovered that HMs content in muscle samples of aquacultured tilapia fish of autumn or summer season and were higher than those of spring or winter season in the sites of El-Max farm (Alexandria Governorate), Al-Manzalah lake (Dakahlia Governorate), Kafr El-Sheikh farms, and Edku lake (Beheira Governorate) and Burullus lakes (Kafr El-Sheikh Governorate).

### 3.3. Seasonal risk assessment for human exposure to HMs in fish

Data of risk assessment of the exposure to the determined

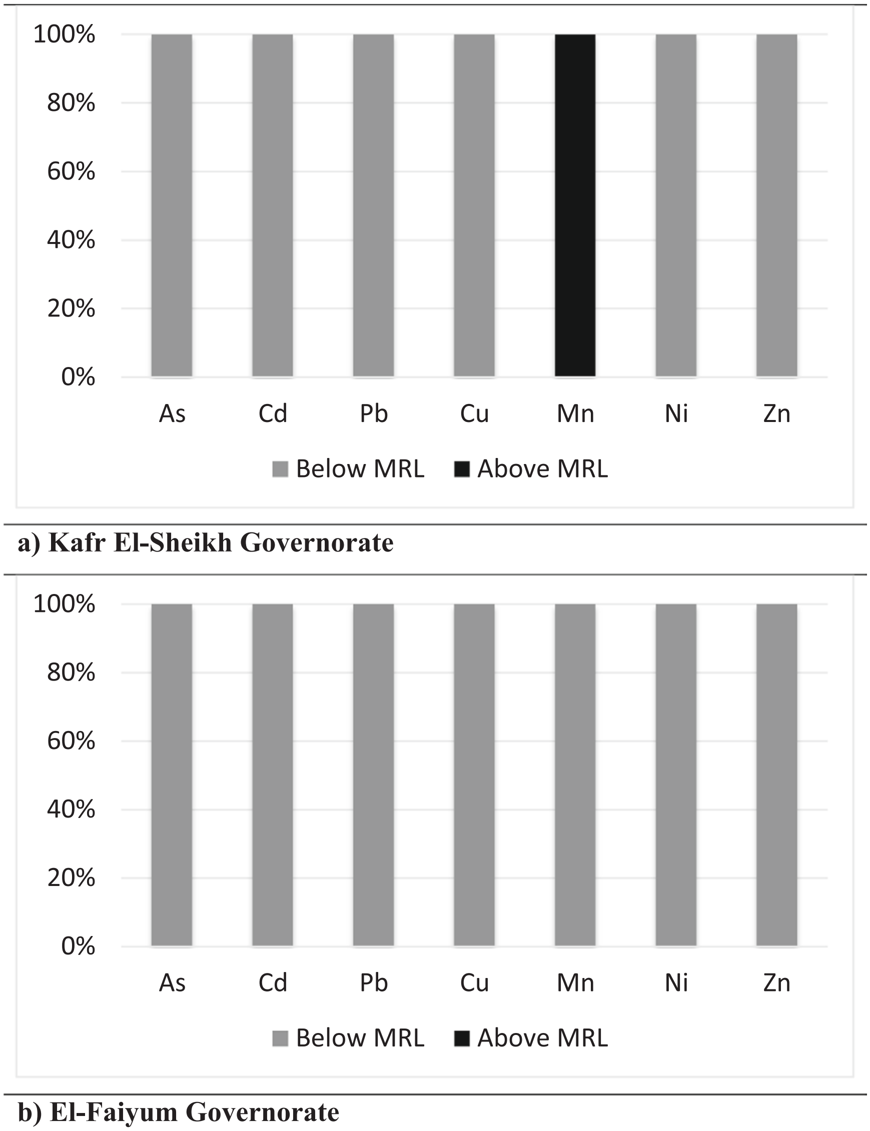


**Fig. 3.** Percentages of HMs' concentration compared to their MRLs (spring 2022). MRLs values (ppm) for As, Cd, Pb, Cu, Ni, Zn and Mn in fish muscles are 0.5, 0.5, 2.0, 20, 10, 40 (EOS [30]) and 0.5 (FAO [29]).

concentrations of HMs in tilapia fish through autumn 2021 and spring 2022 were shown in Tables 4 and 5, respectively. Target hazard quotient (THQ) was calculated individually for every element. Additionally, the total THQ value or HI was calculated for each aquaculture farm as the sum of THQ values concerning HMs in the farm.

Results of season I (autumn 2021), Table (4), revealed that the determined levels of As in fish samples of Kafr El-Shaikh and El-Faiyum farms were found to pose adverse effects to human health at all. Where the THQ values of As substantially exceeded 1 either for Kafr El-Shaikh samples (THQ range: $3.15 \pm 0.5$) or for El-Faiyum samples (THQ range: $2.39 \pm 0.8$). These results indicated that levels of human exposure to As exceeded the reference dose. On the other hand, the THQ scores of other HMs (Pb, Cu, Fe, Mn, Ni, Cr and Zn) in both Kafr El-Shaikh and El-Faiyum farms were lower than 1, which concluding the safety of these HMs as individuals.

The rank order of As THQ values of Kafr El-Shaikh farms were: farm 1 > farm 2 = farm 4 > farm 3 > farm 5. While El-Faiyum farms were ranked in order by their As THQ values as follows: 1 > farm 2 > farm 3 > farm 4 > farm 5. Meanwhile the HI value of the gathered HMs' THQs for every farms exceeded the value of one whole. The rank order of HI values for Kafr El-Shaikh's farms were as follows: farm 4 > farm 2 > farm 1 > farm 5 > farm 3, whereas El-Faiyum farms were ranked as follows: farm 1 > farm 2 > farm 3 > farm 4 > farm 5.

Based on the obtained data of the first season, farms 1 and 2 from Kafr El-Shaikh governorate as well as farms 1 and 2 from El-Faiyum governorate were chosen for the second season of analyzing HMs contents in fish. Due to As' extreme toxicity, this decision was made based on the higher concentrations of As in the chosen farms compared to other farms.

Farms 1 and 2 of Kafr El-Shaikh are located in Al Haddadi zone. El-Naphlah agricultural drainage, which serves as the water supply for farm 1, is also regarded as Farm 1's outlet. However, the source of water supply to farm 2 is El-Mosraniah agricultural drainage. The fact that farm 1 has no outlet may help to explain why farm 1 has the highest degree of HMs pollution, because HMs have been accumulated in the water supply source (El-Naphlah drainage). On the other hand, Qarun Lake, a closed reservoir for the wastewater discharged from the agricultural areas in El-Faiyum governorate, which is heavily contaminated by HMs [26], serves as the water source for farms 1 and 2 of El-Faiyum governorate, which showed the highest HMs values [25].

With regard to results of season II (spring 2022) in Table (5), it was discovered that there were a remarkable reduction in HMs content in

Tilapia fish samples of both governorates as compared to the previous season. However, the same trend line of THQ rank was observed. Where the rank order was as follows: As > Cr > Fe. Meanwhile, all values of either THQ or HI were less than the value of one whole for farms of both governorates. These findings led to the conclusion that there are no potential risks to human health from the exposure to the determined HMs in Tilapia fish samples of the second season.

### *3.4. Comparison of the current study's findings with previous research regarding the presence of heavy metals in cultured tilapia fish of Egypt*

Data of Table (6) summarizes the obtained results of previous studies, as ranges, concerning HMs in farmed tilapia fish of different regions in Egypt as compared with the current investigation. It can be noticed from Table (6) that most of the performed studies on the Egyptian aquacultures did not determine As, Hg, Cr, Mn and Ni as done in the present investigation. In this concern, our results of other elements, includes Cd, Pb, Cu and Zn, in Kafr El-Shaikh samples were comparable to those of Ali et al. and Girgis et al. [39,40]. On the other hand, the reported concentrations by Abumourad and Radwan et al. [5, 41] were slightly lower than the obtained data of this study. This means that the contamination level of HMs in Kafr El-Shaikh farms is increased over the time due the increased anthropogenic activities such as the use of pesticides and chemical fertilizers as well as the industrial wastes that discharged into the canals and drains.

With regard to El-Faiyum farms, El-Tantawy et al. [26] revealed similar ranges of Cd, Pb, Fe, and Zn concentrations in tilapia fish samples from Lake Qaroun and Wadi El-Rayan aquacultures, however Cu concentrations were noticeably higher than ours in the current study. In contrast to our investigation, Abumourad [5] found lower ranges of Cd, Pb, Cu, and Zn values in fish samples from El-Faiyum farms. This also clarify the contamination increase over time in El-Faiyum farms as mentioned above with Kafr El-Shaikh.

Data of Table (6) is also summarizing the different studies conducted between 2008 and 2021 corresponding the different locations other than Kafr El-Shaikh and El-Faiyum. In this regard, tilapia fish samples of Lakes of Edku, Borollus, and Manzala zones contained elevated levels of Cd, Pb, Cu and Ni than those of our detected levels [37,38,42–44]. As well, the studied farms of other coastal governorates such as Damietta and Alexandria governorates contained higher levels of HMs, Fe and Mn in particular, than ours as reported by Abd-El-Khalek et al., Abd El-Samee et al., and Elnimr [36,45,46]**.** These above-mentioned locations lie at the end of Egypt's northern region, close to the canals' and drains' mouths into the Mediterranean Sea. This explains why there are so many heavy metals since they accumulate as we travel further north.

## 4. Conclusion

Results of the present study concluded that Tilapia fish samples of the studied autumn season were highly contaminated with HMs than those of spring season. For the highly toxic elements, it was found that the predominant element was arsenic, while lead and cadmium were the least abundant elements in the studied samples. Notably, mercury element was not detected in all farms of both governorates through the two studied seasons. With regard to qualitative assay, the rank order of the all detected metals, it was as follows: Fe > Zn > Cu > As > Mn > Cr > Ni > Pb in autumn samples, while it was Fe > Zn > Mn > Cu > As in spring samples. Concerning the risk assessment, it was found that values of the hazard index (HI or $\sum$THQ) for the ten farms, in autumn season 2020, were higher than one hole which reflected a potential risk from the consumption of that season's samples. Meanwhile, all HI values of the ten farms' samples, in spring season 2022, were less than one whole, which concluded that there were no potential risks to human health from the exposure to HMs in Tilapia fish samples of spring season. Finally, the present investigation recommends that some mitigation treatment programs are required to reduce the contamination levels by HMs in aquaculture water in such contaminated aquacultures.

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**Table 6**
Comparison of the current study's findings with earlier research regarding the presence of heavy metals in tilapia fish.

| Different studies | Site No. | As | Cd | Pb | Hg | Cu | Fe | Mn | Ni | Cr | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Current study (Kafr El-Sheikh) | **1** | 0.13–1.68 | <d.l – 0.01 | <d.l.– 1.38 | <d.l. | 0.78–2.38 | 13.2–375.3 | 0.58–26.75 | <d.l.- 1.00 | 0.78–2.26 | 6.34–42.75 |
| Current study (El-Faiyum) | **11** | 0.10–1.50 | 0.01–0.02 | <d.l.– 0.10 | <d.l. | 0.47–1.50 | 12.77–160 | 0.44–9.25 | <d.l.- 0.75 | <d.l.- 2.00 | 0.48–51.25 |
| Radwan [41] | **1, 2** | 0.15–0.73 | 0.03–0.20 | 0.20–0.62 | ——— | 0.12–0.38 | 7.64–11.28 | ——— | ——— | ——— | 2.55–3.41 |
| Morshdy [11] | **3, 4** | ——— | 0.04–0.11 | 0.38–0.72 | ——— | ——— | ——— | ——— | ——— | ——— | ——— |
| Yacoub (2021) [43] | **3** | ——— | 0.4–1.1 | 1.5–3.3 | ——— | 2.0–4.2 | 36.4–83.9 | 2.9–6.9 | 4.39–6.01 | ——— | 28.5–41.5 |
| Farouk [38] | **2, 5** | ——— | 0.16–0.41 | 0.20–0.72 | ——— | ——— | 55.6–82.8 | 8.2–16.6 | ——— | ——— | 16.9–23.3 |
| Abdel-Halim [42] | **5** | ——— | <d.l.- 39.3 | 3.7–46.6 | ——— | 613–760 | ——— | 25.0–30.8 | 3.3–46.0 | 7.4–54.9 | 26.6–31.0 |
| Abd El-Samee [45] | **6** | 0.16–0.50 | 0.001–0.07 | 0.09–1.42 | 0.01–0.94 | 2.03–16.68 | 62.5–336.9 | 6.05–54.15 | ——— | ——— | 30.0–96.3 |
| Girgis [39] | **1** | ——— | < 0.05 | < 0.05–1.80 | ——— | < 0.05–2.2 | ——— | ——— | ——— | ——— | 10.7–50.0 |
| Khalifa [47] | **7, 8** | ——— | <d.l.– 0.22 | <d.l-0.63 | <d.l-1.26 | ——— | ——— | ——— | ——— | ——— | ——— |
| El-Batrawy [9] | **2** | ——— | ——— | 0.21–0.81 | ——— | 0.28–0.53 | 6.4–17.7 | 0.21–1.34 | 0.43–0.64 | ——— | 3.64–6.23 |
| Ali [40] | **1** | ——— | <d.l. | <d.l. | ——— | 2.20–6.25 | 111–163 | ——— | ——— | ——— | 28.2–88.3 |
| Omar [48] | **7, 8** | ——— | 0.01–0.09 | 0.05–2.07 | ——— | 2.19–8.89 | 13.8–145.0 | 0.36–4.45 | ——— | ——— | 20.5–55.8 |
| Badr [49] | **9, 10** | ——— | 0.009–0.024 | 0.66–0.83 | ——— | 0.26–0.69 | 5.37–31.53 | 0.15–0.23 | ——— | ——— | 0.90–6.99 |
| Abumourad [5] | **1, 11** | ——— | 0.002–0.004 | 0.01–0.02 | ——— | 0.001–0.002 | ——— | ——— | ——— | ——— | 0.022-.033 |
| Abd-El-Khalek [36] | **12** | ——— | 0.08–0.74 | 3.8–16.5 | ——— | 2.4–66.7 | 69.5–594.3 | ——— | ——— | ——— | 4.8–27.0 |
| Yacoub (2012) [37] | **3** | ——— | ——— | 9.0–20.0 | ——— | 2.1–14.8 | ——— | 2.8–38.0 | ——— | ——— | 11.0–66.0 |
| Elnimr [46] | **6** | 0.21–0.50 | 0.01–0.04 | 0.09–1.41 | 0.009 | 2.64–16.68 | 62.5–331.2 | 23.4–54.2 | ——— | ——— | 29.9–96.3 |
| Saeed [44] | **2, 3, 5** | ——— | 0.014–10.4 | 0.016–10.1 | ——— | 1.77–48.84 | 21.4–256.7 | 0.23–22.98 | ——— | ——— | 9.9–212.4 |
| El-Tantawy [26] | **11** | ——— | 0.13–0.43 | <d.l.- 0.54 | ——— | 2.59–19.75 | 28.3–152.7 | ——— | ——— | ——— | 14.3–65.9 |

1, Kafr El-Sheikh Farms; 2, Burullus Lake; 3, Manzala Lake; 4, El-Husseiniya (Sharkia); 5, Edku Lake and Farms; 6, Damietta Farms; 7, Cairo markets; 8, Giza markets; 9, El-Tebeen district; 10, El-Zamalek district; 11, El-Faiyum Farms; 12, El-Max Farms (Alexandria).

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### CRediT authorship contribution statement

Project administration, funding acquisition, resources, study designing, risk assessment calculations were done by M.B.M. Ahmed. All authors contributed to the study conception and design. Material preparation, data collection and analysis, data handling were performed by G.N. Abdel-Rahman, M.E.M. Ali, E.M. Saleh, O.M. Morsy, M.R. Elgohary, M.M. Saad and Y.M. Awad. All authors contributed in the preparation and revision of the final version of the manuscript.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Data will be made available on request.

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