Research Article

Evaluation of Heavy Metals Accumulated in Some Aquatic Species Collected Along the Suez Refineries to El-Sokhna Area

E. A. Omayma*, A. M. Sawsan, A. F. Nazik
Egyptian Petroleum Research Institute, Nasr City, Cairo, Egypt.
***Corresponding author's E-mail:** dr.omaymamosa@yahoo.com

Accepted on: 25-08-2015; **Finalized on:** 30-09-2015.

ABSTRACT

The concentrations of heavy metals (Al, Zn, Pb, Cu, Fe, Mn, Mo, Ni, V, Cr, Co, Cd, Mg, Ca and Sr) were measured in the liver, gills and muscles of ten benthic and pelagic fish species collected along the Suez refineries to El-Sokhna area at the Suez Gulf. The levels of heavy metals were measured using Inductive Coupled Argon Plasma (ICAP) after digestion of the samples by kjldahl heating digester, concentrations of heavy metals varied significantly among fish species and organs. As expected, muscles always possessed the lowest concentrations of all metals compared to both of liver and gills. In most studied fish, the liver was the target organ for Zn, Pb, Fe, Co, Cr, Cd and Mo accumulation. Al, Cu, Mn, Ni, V, Mg, Ca and Sr however, exhibited their highest concentrations in the gills. Additionally, there were great variations among heavy metal levels in muscles of the fish species. The estimated levels of all metals in the present study were lower than the limits permitted by Food and Agriculture Organization of the United Nations / World Health Organization (FAO/WHO), European Community Regulation (EU), the United Kingdom Ministry of Agriculture, Fisheries and Food (MAFF), Turkish and Saudi guidelines, Lead and cadmium concentrations however, exceeded the permissible limits in fish proposed by EU limits in *Sauridaundo Squamous* and in *Rhabdosargus Haffar* by both European Commission (EC) and England. The estimated daily intakes (EDI) of all metals (µg/day/person) through consumption of the fish species by Suez people were well below the permissible tolerable daily intake for 70 kg person (PTDI70) set by FAO/WHO. Therefore, it can be concluded that no problems on human health would be raised at present from the consumption of fish muscles from the Suez Gulf.

Keywords: Suez Gulf, Heavy metals, ICAP, Fish, Consumption safety.

INTRODUCTION

In the recent years, world consumption of fish has increased simultaneously with the growing concern of their nutritional and therapeutic benefits. In addition to its important source of protein, fish typically have rich contents of essential minerals, Vitamins and unsaturated fatty acids[1]**.** The American Heart Association recommended eating fish at least twice per week in order to reach the daily intake of omega-3 fatty acids[2]. However, fish are relatively situated at the top of the aquatic food chain; therefore, they normally can accumulate heavy metals from food, water and sediments[3]. The content of toxic heavy metals in fish can counteract their beneficial effects; several adverse effects of heavy metals to human health have been known for long time[4]. This may include serious threats like renal failure, liver damage, cardio vascular diseases and even death[5]. Therefore, many international monitoring programs have been established in order to assess the quality of fish for human consumption and to monitor the health of the aquatic ecosystem[6]. In the last few decades, the concentrations of heavy metals in fish have been extensively studied in different parts of the world[7]. Most of these studies concentrated mainly on the heavy metals in the edible part (muscles). However, other studies reported the distribution of metals in different organs like the liver, kidneys, heart, gonads, bone, digestive tract and brain. According to the literatures, metal bioaccumulation by fish and subsequent distribution in organs is greatly inter-specific. In addition, many factors can influence metal uptake like sex, age, size, reproductive cycle, swimming patterns, feeding behavior and living environment (geographical location)[8]. Red Sea is a semi-enclosed tropical body of water. It has been considered to be a relatively unpolluted marine environment. In the last few decades, however, evidence of heavy metal pollution has been found in various locations[9]. In the northern part of the Egyptian Red Sea, increasing population growth and industrial activities in Suez City are the main sources of heavy metal pollution. While in the southern part, the tourism industry and shipping of ores are the major sources of the anthropogenic input of heavy metals. Some authors[10] studied the characteristics of the inlet and the Outlet effluents from attaqa power station poured in Suez bay through two trips at 2003 and 2004, the recorded concentration of iron, Zinc, Copper, Aluminum, Chromium and Lead are all within in the permissible limits. In Egypt, the Red Sea is of great ecological interest; it is an important source of fisheries and tourism industry. In spite of that, heavy metals' studies in the Red Sea are restricted. Relatively few studies investigated the levels of metals in some fish species from the Red Sea[11]. However due to increasing anthropogenic and industrial stress on Suez bay, continuous monitoring of the environmental conditions of the Red Sea and Suez bay are required.

In the present study, levels of heavy metals in the organs of some commercial fish from landing areas on the Suez Gulf were determined, aiming to evaluate the current environmental status of this broad section of the Gulf.

Additionally, metals' content in muscle were compared against the international standards and guidelines to assess the quality of fish for human consumption beside, evaluation for human uses according to provisional tolerable daily intake.

MATERIALS AND METHODS

Area of Study on the Suez Gulf

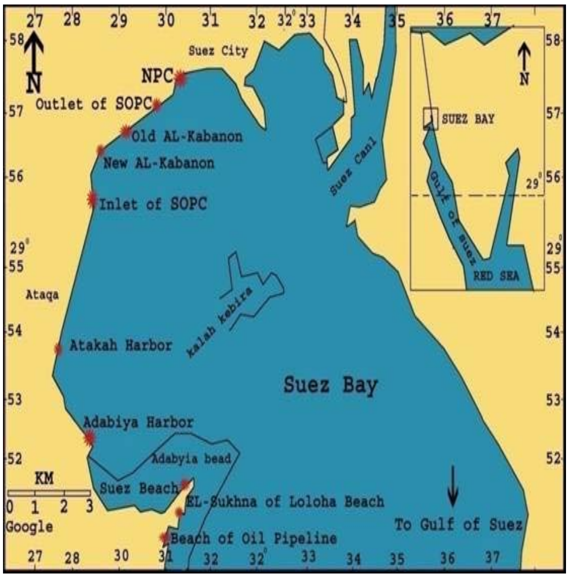


Figure 1: Map of study area, showing sample points along the Suez Gulf, Egypt

Comprises the important parts of Suez Canal, which includes industrial and agricultural regions (Suez oil processing company, Al–Nasr Oil Company, Old and New Al-Kabanon, Atakah and Adabiya Harbors, and beaches in El- Sukhna area), the areas of investigation are described as follow Suez Bay, the Suez bay is the entrance of Red sea and is limited by latitudes 29° 54` and 29° 57` N, and longitudes 32° 28` and 32° 34` E. **Fig. (1)**. the adjacent land area of the Red Sea is mostly arid or semi-arid region. It is an important shipping route for oil tankers and other ships traveling through the Suez Canal[12].

Sample Collection and Storage

Ten species were collected in January **2015** from the Suez Gulf seashore, which were purchased from fishermen operating small crafts within a 22 km radius in the area which extends from the Suez refineries up to El- Sukhna area, fish species **Fig. (2)** were labeled, stored in ice at -20 °C and the same day transported to the laboratory for further treatment and analysis. Prior to analysis, length and weight of the fishes were determined. The range of lengths and weights of the fish species, the numbers of individual fish species as well as the sampling sites are presented in **Table (1).**

The muscle, liver and gill tissues were separated, weighed, and then deep frozen**.** Subsequently, dissected tissues of the fish specimens were dried in an oven at 105°C and stored in vacuum desiccators.

Trace Metals in Fish Samples

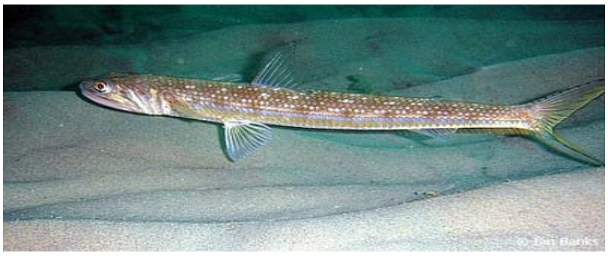
The dried organs were weighed accurately to the fourth decimal in a digestion vessel of 15 ml capacity kjldahl digestion tubes. 4 c.c. of A.R. 65 % concentrated HNO_3 was added to the samples. The vessel was placed in a digestion block, which has a capacity of nine vessels. The digestion block was placed on a hot plate at 120°C for two hours. The block was then left over night for cooling[13]. It was insured that the digestion conditions were followed exactly; this is being achieved when the solution was being clear after cooling. The solution was filtered using Wattman No. 42 filter paper and kept in a polyethylene bottle previously cleaned with nitric acid and rinsed with distilled water. The contents of each tube was then transferred to a measuring flask and diluted with distilled water-cool, Al, Zn, Pb, Cu, Fe, Mn, Mo, Ni, V, Cr, Co, Cd, Mg, Ca and Sr concentrations were estimated using Atomic Emission Argon Plasma Spectroscopy.

Metal in fish samples can be determined by (ICAP) 6500 Duo. Thermo Scientific, England, 1000 mg/L multi-element Certified standard solution, Merck, Germany was used as stock solution for instrument standardization. A great advantage of ICAP emission spectroscopy as applied to environmental analysis is that several metals can be determined simultaneously by this method[14]. At each step of digestion processes, acid blanks (laboratory blank) were prepared in order to ensure that the samples and chemicals used were not contaminated. They were analyzed by (ICAP) before using and their values were subtracted to ensure that the equipment read only the exact values of heavy metals. Each set of digestion has its own acid blank and was corrected by using its blank.

RESULTS AND DISCUSSION

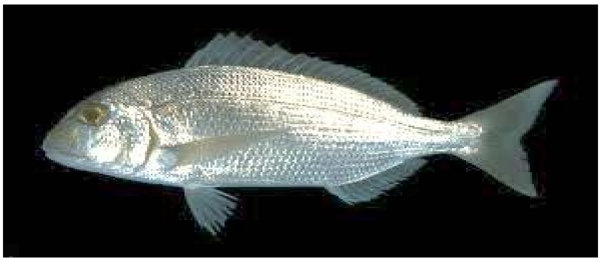
Accumulation Levels of Trace Metals in Fish Considering Feeding Habits

Concentrations of heavy metals (Al, Zn, Pb, Cu, Fe, Mn, Mo, Ni, V, Cr, Co, Cd, Mg, Ca and Sr) in the muscle, liver and gill of fish collected from different ten sites on Suez Gulf **Table (2).** All results are converted from dry weight, to wet weight using converting factor 0.3[15]. Accumulation patterns of all metals were significantly different between the different species, organs and sites. All fish contained the lowest concentrations of metals in muscle, while, almost all fish species showed the high concentrations of Zn, Pb, Fe, Mo, Cr, Co and Cd in the liver, and the highest concentrations of Al, Cu, Mn, Ni, V, Mg, Ca and Sr in the gill. The highest concentrations fluctuated between the liver in some species and gill in others, while muscle significantly possessed the lowest concentration of all metals. Regarding the geographical variation of metals, there were different concentrations of metals in all fish species when compared to other sites **Table (3).** The accumulation of metals in different species showed significant inter-specific variations. However it can be noticed that, different organs exhibited different patterns in metals accumulation.



***Sauridaundo squamis*/Brushtooth lizard fish**

***Euthynnus affinis*/Kawakawa**



***Rhabdosargus haffara*/Haffara Sea bream**

***Argyrops spinifer*/Porgies**

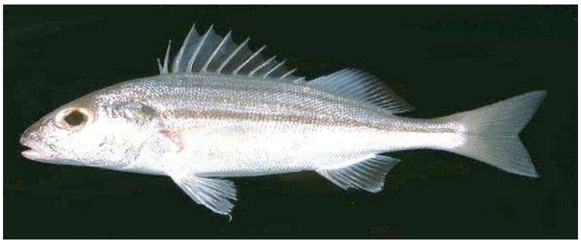
***Nemipterus japonicus*/Japanese Threadfin bream**

***Oreochromis niloticus*/Nile tilapia**

***Trachurus indicus*/Horse mackerel**

***Peneus japonicas*/Red mullets**

***Scomber japonicus*/Chub Mackerel, Pacific mackerel or Blue mackerel**



***Pomadasys stridens*/Striped piggy**

Figure 2: Photographs of ten aquatic species collected from the Suez Gulf

Table 1: The ecological characteristics and recorded morphometric measures of examined Fish species

Code	Stations	Scientific name	English name	Feeding habits	Biotype complex	No.	Length (cm)	Body weight (g)
1	AL- Nasr Oil Company (NPC)	***Sauridaundo squamis***	*Brushtooth lizard fish*	Carnivore (small fish)	Demersal, (benthic)	**7**	14	400
2	Outlet of Suez Oil Petroleum company (SOPC**)**	**Euthynnus affinis**	*Kawakawa*	Feeds on small fish, squids, and sometimes zooplankton.	found in open waters but always close to the shoreline	1	40	350
3	Old Al-Kabanon	***Rhabdosargus haffara***	*Haffara sea bream*	Feeds on benthic invertebrates. Consumed fresh.	Inhabits shallow waters, mainly around coral reefs, and over sandy or mud-sandy bottoms	4	13.5	420
4	New Al-Kabanon	***Argyrops spinifer***	*Porgies*	Feeds on benthic invertebrates, mainly mollusks. Important food fish.	Inhabits a wide range of bottoms. Young fish occur in very shallow waters of sheltered bays; larger individuals in deeper water	4	15	480
5	Inlet of Suez Oil Petroleum Company (SOPC)	***Nemipterus japonicus***	*Japanese threadfin bream*	Carnivore (small fish, invertebrates polychates)	Demersal	5	18	425
6	Atakah Harbor	***Oreochromis niloticus***	*Nile Tilapia*	Herbivorous (feed on phytoplankton)	benthic and pelagic due to air bladder	3	14.5	389
7	Adabiya Harbor	***Trachurus indicus***	*Horse Mackerel*	Carnivore (invertebrates and fish)	Pelagic	4	24	431
8	Suez Beach	***Peneus japonicas***	*Red mullets*	Prey of small fish and crustaceans	inhabit the inshore area and coral reefs, can be found on a range of sea beds including sand, mud and coarse gravel	8	11.5	450
9	El- Sukhna of Loloha Beach	***Scomber japonicus***	*Chub mackerel, Pacific mackerel or blue mackerel*	feed on copepods and other crustacean, fishes and squids	A coastal pelagic species, to a lesser extent epipelagic to mesopelagic over the continental slope	4	21	470
10	Beach of oil pipeline	***Pomadasys stridens***	*Striped piggy*	Feeding on a variety of crustaceans, mollusks and small juvenile fishes, called a predator.	Living in the reef environment and sandy	3	13.5	495

No: number of sample

© Copyright protected. Unauthorised republication, reproduction, distribution, diss

Therefore, the concentration of metals between species was analyzed in different organs; all results showed significant variations between species. Furthermore, all fish collected from different sites show significantly different concentrations of accumulated metals. In the liver, the herbivore *Oreochromis niloticus* accumulated the highest concentration of Cu (9.118 µg /g wet wt) **Table (2).** Also, the Carnivore *Nemipterus japonicus* accumulated the highest concentration of 5.396 µg/g wet wt; while another Carnivore species *Scomber japonicus* showed the lowest values of 1.317µg/g wet wt. Gills showed a wide range of Cu levels and recorded concentrations from 0.4185 µg/g wet wt *(Euthynnus affinis*) to 146.082 µg/g wet wt *(Scomber japonicus*) **Table (4)**. Concentrations of Cu in muscle *(Peneus japonicas*) ranged from 0.0061 to 2.184µg /g wet wt (*Euthynnus affinis*), *Euthynnus affinis* exhibited a tendency to accumulated high concentration of Zn in the liver when compared to other species (113.879 µg/g wet wt). **Table (**2) showed that*,* *Scomber japonicus* recorded the highest concentration of Zn in gill (135.771 µg/g wet wt), while the highest concentrations of Zn in muscle were recorded in *Euthynnus affinis* (9.520 µg/g wet wt).

On the other hand, the Carnivores *Sauridaundo squamis* and *Rhabdosargus haffara* recorded identical values (25.595, 25.333 µg/g wet wt), this indicates a good matching agreement for Zn concentrations in gill respectively. Concentrations of Pb in gills ranged from 0.0192 (*Euthynnus affinis*) to 1.330 µg/g wet wt **(***Sauridaundo squamis***).** Liver showed a wide range of Pb levels ranging from 0.0192 (*Peneus japonicas)* to 4.134 µg/g wet wt **(***Sauridaundo squamis***)**. Good matching between *Euthynnus affinis, Peneus japonicas and Scomber japonicus species* ; have the same values 0.0192 µg/g wet wt, while the concentrations of Pb in muscle ranged from 0.0149 (*Nemipterus japonicus*) to 0.1340 µg/g wet wt (*Sauridaundo squamis).* Liver showed a wide range of Cd concentrations among the studied fish, a very low Cd concentration (0.0358 µg/g wet wt) was recorded in (*Peneus japonicas*), and an extremely high concentration (2.058 µg Cd/g wet wt) was observed in the liver of (*Euthynnus affinis)* **Table (2)**. In gill, Cd levels varied between 0.0583 (*Peneus japonicas)* and 0.3771µg/g wet wt (*Nemipterus japonicus*). Cd concentrations in the muscles ranged from 0.0107 (*Oreochromis niloticus*) to 0.4095 µg/g wet wt in (*Rhabdosargus haffara*). In liver, Fe concentrations were found to be between 0.3410 and 239.781 µg/g wet wt (*Rhabdosargus haffara*) and *(Oreochromis niloticus*), respectively. The concentrations of Fe in gill ranged from 59.362 (*Nemipterus japonicus*) to 234.653µg/g wet wt (*Euthynnus affinis)*. Muscle recorded Fe concentrations from 4.880 (*Scomber japonicus*) to 51.009µg/g wet wt (*Argyrops spinifer*). Manganese concentrations in gill showed a wide variation and ranged between 1.131 (*Euthynnus affinis*) and 9.771 µg/g wet wt (*Nemipterus japonicus*). In liver, concentrations of Mn ranged from 0.4164 (*Oreochromis niloticus*) to 3.282 µg/g wet wt (*Pomadasys stridens*). Fish muscle recorded the lowest concentrations of Mn which ranged between 0.2014 **(***Trachurus indicus***)** and 0.5664 µg/g wet wt (*Nemipterus japonicus*). Heavy metal concentrations in each of the three analyzed tissues show that Co, Cr, Mo concentrations were higher in liver than both gill and muscle their concentrations were 0.0359-0.4551, N.D - 0.2882 and 0.0243-0.2924 µg/g wet wt respectively. On the contrary, Ni and V reported higher values ranged from 0.0796-0.9417, N.D - 0.8952 with mean concentrations 0.3246 and 0.1986 µg/g wet wt, respectively in gill as indicated from **Fig. (3) & Table (4)** showed that**,** Al, Ca, Mg, and Sr concentrations in gill exceeded than their concentrations in muscle and liver tissues. **Fig.(3) and Table (**4) showed also that, Al 5.217-103.950 with mean concentrations 53.399, Ca 4646.716-12928.546 with mean concentrations 8242.142; Mg 401.296-1138.475 with mean concentrations 649.080 and Sr 35.925-170.879 µg/g wet wt. with mean concentrations 91.240 µg/g wet wt.

Variations in Organs Ability to Accumulate Metals

Fish species showed that, the lowest concentrations were in the muscle and the highest were in the gill and liver **Table (4), Fig. (3)**. A pattern of significantly higher heavy metals accumulation in liver than in the muscle was detected in many studies[45]**.** In the present, liver had significantly higher heavy metals and trace element concentrations than the muscle. The difference in accumulation potential between these two tissues can be explained by the activity of metallothioneins, proteins that are present in liver but not in the muscle, which have the ability to bind certain heavy metals and thus allow the tissue to accumulate them at a high degree[46] all over, Fe tends to accumulated in hepatic tissues due to the physiological role of the liver in blood cells and hemoglobin synthesis[47]. On the other hand, the liver also showed high levels of non-essential metals such as Pb, Cd; this finding could be explained by the ability of Cd to displace the normally MT-associated essential metals in hepatic tissues[48]. Similar results of high Zn, and Cd in the liver were observed in several field studies[49,50]. Zn, Pb, Fe, Mo, Cr, Co and Cd, were highest in the liver. Similar results for high Pb concentrations in liver were recorded[51], Lead regarded as one of the most toxic metals to aquatic organisms; it is an environmental contaminant that can cause serious damage to human health. It competes with calcium (Ca^{+2}) at enzymatic locations in organisms.

The main exposure route of non-occupationally exposed individuals is food consumption[52]. Like Pb, Cd is also a non- essential element that competes with calcium (Ca^{+2}) at enzymatic locations in organisms. The concentrations of Cr did not exceed the maximum allowable concentration. In humans, a Cr deficiency can result in disturbances of the metabolism of glucose and lipids. The average human requires an estimated 1 mg/day of Cr[53].

Table 2: Trace metals concentration (µg/g wet wt) in fish samples determined by ICAP after dry digestion

Elements		**Al**	**Zn**	**Pb**	**Cu**	**Fe**	**Mn**	**Mo**	**Ni**	**V**	**Cr**	**Co**	**Cd**	**Mg**	**Ca**	**Sr**
Fish species																
Sauridaundo squamis	**Muscle**	0.7245	6.262	0.1340	0.1848	9.862	0.3399	N.D	0.1464	N.D	N.D	N.D	0.0558	282.471	1430.886	4.597
	Liver	10.210	37.008	4.134	1.480	45.047	2.143	0.0243	0.1684	0.4494	0.2882	0.2882	0.0656	448.536	6447.745	25.088
	Gill	10.169	25.333	1.330	4.610	68.404	2.795	N.D	0.9417	N.D	N.D	0.0272	0.0670	556.790	10839.818	44.660
Euthynnus affinis	**Muscle**	0.0393	9.520	0.0775	2.184	33.734	0.2134	N.D	0.0910	N.D	N.D	N.D	0.0808	31.202	303.975	1.1613
	Liver	1.427	113.879	1.092	3.114	195.800	0.636	0.2924	0.1548	N.D	0.0452	0.0452	2.058	249.618	361.462	2.582
	Gill	45.553	40.511	0.0192	0.4185	234.653	1.131	N.D	0.0796	N.D	N.D	0.0134	0.1985	586.087	1563.856	35.925
*Rh**abdosargus haffara***	**Muscle**	1.6868	7.342	0.0609	0.2946	9.424	0.4014	N.D	0.1539	N.D	N.D	0.012	0.4095	356.451	809.31	4.570
	Liver	9.641	34.729	0.0951	2.112	0.3410	2.341	0.1491	0.1650	N.D	0.1109	0.1109	0.4356	469.331	1168.987	8.886
	Gill	103.950	25.595	0.0250	0.8883	117.487	8.424	N.D	0.1037	0.1962	N.D	0.662	0.2449	924.650	658.730	130.711
Argyrops spinifer	**Muscle**	7.997	4.579	0.0611	0.3138	51.009	0.3069	0.0267	0.0939	N.D	N.D	N.D	0.0374	380.686	1384.715	7.292
	Liver	28.861	35.920	0.0194	4.454	114.957	2.544	0.1687	0.1614	N.D	0.0359	0.0359	0.1730	1036.937	5224.867	176.191
	Gill	103.895	16.720	0.0219	0.5445	150.777	4.637	N.D	0.2486	0.1968	N.D	0.0405	0.0471	1138.475	8986.396	170.879
Nemipterus japonicus	**Muscle**	5.513	5.455	0.0149	0.3957	16.961	0.5664	N.D	0.0461	N.D	N.D	N.D	0.2639	369.009	102.485	4.096
	Liver	49.066	43.985	0.0170	5.396	110.973	2.948	0.0795	0.2646	N.D	0.1049	0.0491	0.3330	636.479	1058.150	18.010
	Gill	31.547	17.496	0.1219	1.9245	59.362	9.771	N.D	0.4065	N.D	N.D	N.D	0.3771	643.676	12928.546	76.057
Oreochromis niloticus	**Muscle**	0.8799	9.488	0.0214	1.165	13.254	0.4029	N.D	0.1350	N.D	N.D	N.D	0.0107	154.565	111.953	6.809
	Liver	170.741	20.773	0.1341	9.118	239.781	0.4164	0.2334	0.2874	0.7542	0.6246	0.2615	0.0400	186.207	957.441	6.158
	Gill	97.865	26.410	0.2061	0.9462	104.647	6.426	N.D	0.2503	0.895	0.2033	0.0743	0.0235	401.296	4646.716	71.393
Trachurus indicus	**Muscle**	1.301	5.856	0.0507	1.332	15.200	0.2014	N.D	0.14607	N.D	N.D	0.0107	0.0403	264.752	366.947	1.914
	Liver	3.451	29.803	0.3099	1.887	96.942	1.321	0.1005	0.6981	N.D	0.9003	0.1321	0.3639	720.151	4646.603	37.074
	Gill	10.109	23.915	0.0251	1.177	109.306	2.530	N.D	0.1054	N.D	N.D	0.0477	0.1041	578.435	5227.772	79.882
Peneus japonicas	**Muscle**	0.5724	5.856	0.0166	0.0061	15.200	0.2445	N.D	0.0629	N.D	N.D	1.332	0.1090	274.951	1068.842	6.239
	Liver	12.374	38.650	0.0192	2.456	77.019	1.643	0.0445	0.2010	N.D	N.D	0.4551	0.0358	404.163	1974.855	39.884
	Gill	87.666	16.071	0.7086	1.362	128.998	6.002	N.D	0.7710	0.2252	0.5388	0.0451	0.0866	712.3062	12632.401	137.788
Scomber japonicus	**Muscle**	0.0628	7.023	0.0173	0.6903	4.880	0.0476	N.D	0.1155	N.D	N.D	1.332	0.0358	299.806	420.357	2.060
	Liver	1.694	27.673	0.0192	1.317	61.725	0.4965	0.0901	0.0584	N.D	N.D	0.0478	0.1370	329.559	443.829	3.164
	Gill	5.217	135.771	0.8388	146.082	92.163	1.578	N.D	0.1062	0.2082	N.D	N.D	0.0583	502.002	1124.682	77.950
Pomadasys stridens	**Muscle**	2.000	6.831	0.0561	0.4944	8.334	0.3060	N.D	0.0583	N.D	N.D	0.0164	0.0840	234.132	894.552	6.000
	Liver	81.086	32.079	3.945	1.721	134.452	3.282	0.1075	0.3489	N.D	0.1791	0.5316	0.1244	708.637	5133.168	46.454
	Gill	38.015	15.593	0.0655	0.7818	79.592	3.033	N.D	0.2218	0.2910	0.1685	0.0094	0.0715	507.023	6863.712	87.159

N.D: Under the limit of detection; **Al**: Aluminum; **Cd:** Cadmium; **Cr**: Chromium; **Co**: Cobalt**;** **Cu**: Cupper; **Fe**: Iron; **Pb**: Lead; **Mn**: Manganese; **Mo:** Molybdenum; **Ni:** Nickel; **V:** Vanadium; **Zn**: Zinc**,** **Mg:** Magnesium; **Ca:** Calcium; **Sr:** Strontium

© Copyright protected. Unauthorised republication, reproduction, distribution, diss

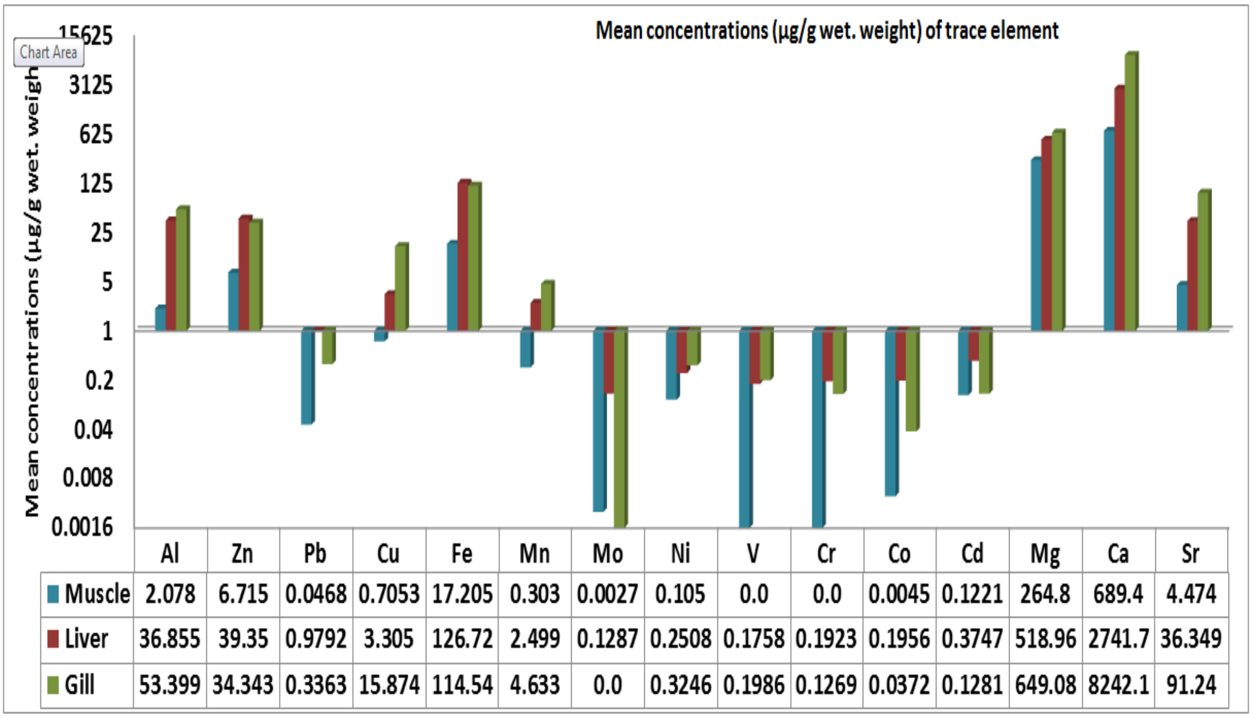
Table 3: Maximum and standard levels in (µg/g) of metals in fish described in literature and range of concentrations found in muscle of fish from Sues Gulf

Elements	Cu	Zn	Pb	Cd	Fe	Mn	Co	Ni	Cr	References
Geographical Areas										
Iranian borders, Persian Gulf [a]	0.1–0.21	3.3–5.8	0.0008–.021	0.0004–0.469	1.9–8.3	0.04-0.24	N.D	0.001–.128	N.D	16
Alexandria [b]	1.59	7.95	0.73	0.25	37.53	0.54	N.D	N.D	N.D	17
Alexandria, Egypt [b]	0.99–1.75	16.53–22.12	0.67–0.99	0.05–0.06	139.8–191.4	0.51–1.66	N.D	0.37	0.74–0.86	18
Alexandria [a]	4	16.70	1.40	1.90	N.D	N.D	N.D	N.D	N.D	15
Taihu Lake [b]	0.228-1.89	16-130	0.177-0.287	0.003-0.021	N.D	N.D	N.D	N.D	ND-0.387	19
Turkey [b]	N.D	38.8– 93.4	0.28– 0.87	0.1– 0.35	36.2– 145	N.D	N.D	N.D	0.63– 1.74	20
China [b]	N.D	2.74– 27.5	0.009– 0.12	0.001– 1.21	2.17– 24.24	N.D	N.D	N.D	0.005– 0.033	21
Canada [b]	N.D	3.4– 53.4	0.005– 0.47	0.005– 0.03	N.D	0.19– 24.3	N.D	N.D	N.D	22
Southwest coast of India [a]	2.06–3.62	26.4–84.3	0.23–0.56	1.25–6.38	333.3–604.75	N.D	0.64–11.8	7.58–13.92	N.D	23
Hurghada [b]	0.28	2.13	0.33	0.02	6.31	N.D	N.D	N.D	N.D	24
China [b]	N.D	3.75– 62.4	0.006– 0.045	0.001– 0.034	0.275– 12.3	0.215– 3.63	N.D	N.D	0.054– 0.102	25
Hurghada b	1.03	N.D	1.07	N.D	33.1	0.12	N.D	N.D	N.D	26
Brazil [b]	N.D	0.06– 39.3	0.01– 1.7	0.001– 0.3	0.4– 26.1	0.07– 7.3	N.D	N.D	N.D	1
Gaza Strip (Palestine) b	0.251–0.907	3.705–20.535	ND-0.552	ND-0.090	ND	0.376–0.834	ND	0.453–0.978	N.D	27
Red Sea [a]	1.7-39.6	8.4-195	0.05 -1.3	0.16 – 3.6	N.D	N.D	N.D	N.D	N.D	9
Sweden [b]	9.61– 19.5	N.D	ND– 0.02	0.02– 0.04	5.85– 14.3	0.49– 1.23	N.D	N.D	0.23– 0.37	28
Homira b	0.02–1.10	3.45–15.1	0.03–0.88	0.001–0.039	1.23–153	0.056–1.56	0.01–0.20	N.D	N.D	3
Red Sea [a]	0.4	N.D	0.89	0.45	N.D	N.D	N.D	N.D	N.D	29
Dhaka, Bangladesh [a]	8.33–43.18	42.83–418	1.76–10.27	0.09–0.87	N.D	9.43–51.17	N.D	0.69–4.36	0.47–2.07	30
Gulf of Aqaba [a]	0.28	9.13	4.80	0.97	5.93	1.63	N.D	N.D	N.D	31
Red Sea [b]	0.66	3.37	0.53	0.17	N.D	N.D	N.D	N.D	N.D	32
Iskenderun Bay b	1.239-2.201	3.025-4.873	1.808.3.474	0.831-1.341	N.D	N.D	N.D	N.D	1.309-2.719	33
Red Sea (Jordan)[a]	0.5–2.0	1.9–35.0	1.5–8.3	0.5–2	N.D	1.0–3.3	N.D	1.0–5.0	1.0–10.3	34
Jeddah coast [a]	0.13	3.9	1.03	0.13	N.D	N.D	N.D	N.D	N.D	35
China , Taihu Lake, Jiangsu [a]	N.D	14.0– 175.7	0.024– 0.242	0.003– 0.151	1.86– 51.6	1.11– 17.8	N.D	N.D	0.285– 0.518	25
Nigeria [a]	0.33–0.92	1.15–7.19	0.05–2.82	0.04–0.58	6.45–26.90	2.30–3.84	0.11–2.17	1.33–11.33	0.49–3.79	36
Red Sea, Suez Gulf [b]	0.17-0.77	2.70-8.23	0.25-0.50	0.04-0.38	1.15-10.92	0.10-0.93	N.D	N.D	N.D	37
European Community [b]	--	--	0.2	0.05	-	--	-	--	-	38
England [b]	20	50	2.0	0.2	-	--	-	--	-	39
FAO (1983)[b]	30	30	0.5	--	-	--	-	--	1	40
Turkish guidelines [b]	20	50	1	0.1	-	20		--	-	41
FAO/WHO limits b	30	40	0.5	0.5	100	--	-	--	50	42
EU limits [b]	10	--	0.1	0.1	-	--	-	--	-	43
Saudi Arabia [b]	--	--	2.0	0.5	-	--	-	--	-	44
Range of metals in Suez Gulf [b]	0.0061 - 2.184	4.579 - 9.520	0.0149 - 0.1340	0.0107 - 0.4095	4.880- 51.009	0.0476-0.4029	N.D - 0.0164	0.0461-0.1539	N.D	Present study

Dry wt [a], Wet wt [b].

Table 4: Concentrations (µg/g wet wt) of trace metal range (minimum–maximum) and mean in muscle, liver and gill.

Tissues	Muscle		Liver		Gill	
Elements	Range	Mean	Range	Mean	Range	Mean
Al	0.0393-7.997	2.078	1.427-170.741	36.855	5.217-103.950	53.399
Zn	4.579-9.520	6.715	20.773-113.879	39.350	16.071-135.771	34.343
Pb	0.0149-0.1340	0.0468	0.0192-4.134	0.9792	0.0192-1.330	0.3363
Cu	0.0061-2.184	0.7053	1.317-9.118	3.305	0.4185-146.084	15.874
Fe	4.880-51.009	17.205	0.3410-239.781	126.721	59.362-234.653	114.539
Mn	0.2014-0.5664	0.3030	0.4164-3.282	2.499	1.131-9.771	4.633
Mo	N.D-0.0267	0.0027	0.0243-0.2924	0.1287	N.D	N.D
Ni	0.0461-0.1539	0.1050	0.0584- 0..3489	0.2508	0.0796-0.9417	0.3246
V	N.D	N.D	N.D-0.7542	0.1758	N.D-0.8952	0.1986
Cr	N.D	N.D	N.D-0.2882	0.1923	N.D-0.5388	0.1269
Co	N.D-0.0164	0.0045	0.0359-0.4551	0.1956	N.D-0.0743	0.0372
Cd	0.0107-0.4095	0.1221	0.0358-2.058	0.3747	0.0583-0.3771	0.1281
Mg	31.203-380.686	264.802	186.207-1036.937	518.962	401.296-1138.475	649.080
Ca	102.485-1430.886	689.402	361.462-6447.745	2741.711	4646.716-12928.546	8242.142
Sr	1.1613-7292	4.474	2.582-176.191	36.349	35.925-170.879	91.240



	Al	Zn	Pb	Cu	Fe	Mn	Mo	Ni	V	Cr	Co	Cd	Mg	Ca	Sr
■ Muscle	2.078	6.715	0.0468	0.7053	17.205	0.303	0.0027	0.105	0.0	0.0	0.0045	0.1221	264.8	689.4	4.474
■ Liver	36.855	39.35	0.9792	3.305	126.72	2.499	0.1287	0.2508	0.1758	0.1923	0.1956	0.3747	518.96	2741.7	36.349
■ Gill	53.399	34.343	0.3363	15.874	114.54	4.633	0.0	0.3246	0.1986	0.1269	0.0372	0.1281	649.08	8242.1	91.24

Figure 3: Histograms representing mean concentration (µg/g wet wt) of trace metals in different tissues of Aquatic species

Based on the results in the present study, approximately 5 g of dry fish (20g wet weight) would provide the required Cr intake per day, even when consuming the fish species with the lowest Cr concentration. Excessive Cd exposure may give rise to renal, pulmonary, hepatic, skeletal, and reproductive toxicity effects and cancer[54]. Also**,** some studies[55] reported that fish's hard tissues had consistently higher accumulations of Mn than soft tissues. While muscle tissue is the main edible fish part and can directly influence human health had the lowest concentrations of most of the analyzed elements, heavy metal concentrations in muscle samples were on the average more uniform than in liver and gill samples. While, Gill is a principal tissue for concentrating trace metals, due to the direct contact between it and dissolved pollutants. The relationship between the fish body weight and gill metal concentrations characterizations the accumulation of different metals[56]. Gills are the main route of metal ion exchange from water[54] as they have very large surface areas that facilitate rapid diffusion of toxic metals[57]. The large surface area of gill that acts as a barrier between the internal and external environmental of marine organism beside, differences in gill binding affinity for metals. Therefore, it is suggested that metals accumulated in gill are mainly concentrated from water; this is in agreement with the findings of[58]. Gill were mostly differentiated by high concentrations of Al, Cu, Mn, Ni, V, Sr, Mg, and Ca. Gill are the major site of Al absorption[59] and the main pathway of Sr uptake from the water[60]. Sr has the ability to facilitate the uptake of Ba in fish residing in the brackish water. High heavy metal loads in gill can point out the water as the main source of contamination[61]. Concentrations of heavy metals in gill can be influenced by absorption of metals onto the gill surface, as well as by formation of complexes between the metals and the mucous, which is often impossible to be removed from lamellae prior to the analysis. The highest content of Mg in gill that was detected in this study is in accordance with some reported[62,63]. More Ni is accumulated in gill tissue of fishes than in the liver[64], concentration in gill may indicate that Ni introduced to the Gulf associated with the chronic inputs of oil pollution to sediment or sedimentary have higher affinity for Ni than gill. Fish showed the highest Cu accumulation in gill when exposed to lethal or sub-lethal concentration. Complexation of metals by coordinate linkages with appropriate organic molecules in biological tissues is an important process involved in metals accumulation by aquatic organisms. Fish respirators systems differ from all other systems because damage to gill has immediate impacted on the rest of fish. Other studies indicated[65] significant correlation between gill-metal concentrations and whole body weight.

Inter-Specific Variations in Metal Accumulation

Table (1) showed that, the collected aquatic fish have different habitat and various morphometric parameters. The present results showed that fish exhibited wide inter-specific variations in metal accumulation in all organs. Many studies attributed the high metal accumulation to the feeding habit of the fish. For instance, some studies[17] display that because *S. rivulatus* is herbivore, it accumulates higher concentrations of metals in their muscles than the carnivore. This suggestion was not a reasonable cause for high metal accumulation in the current study since *Oreochromis niloticus* feeds on phytoplankton recorded the lowest concentration of total metals compared to the other species **Table (2).** Alternatively, some reported[5] suggested that, high Cd concentration in muscle of *yellow fine tuna T. albacores* due to their feeding at the higher trophic levels (carnivorous); however metal accumulations in carnivorous fish were not consistently the highest recorded in the present study in some species which showed a tendency to accumulate metals (Zn, Pb and Fe) in the liver with relatively high concentrations. Apart from previous suggestions, feeding habit may be one reason of metal variation in the *Euthynnus affinis* which accumulated relatively high concentrations of all metals in muscle and exhibited ability to accumulate Mn with high concentrations in all organs. These could be linked to feeding on zooplankton. Since it is the most likely biota compartment for Zn and Cu concentration[66] also generalized that bony tissues of plankton-feeding fish concentrated manganese to a greater extent than benthos feeders[55]. It was interesting to note that all species showed very high concentrations of Cd in organs **Table (2).** This finding can be linked to the age of the fish; since Cd is difficult to be excreted from liver once it is accumulated[17]. *Euthynnus affinis* is the large fish (length 40 cm, weight 350 g) likely accumulated high Cd (2.058ug/g wet wt) concentrations throughout its long life. This agrees with the suggestions[55] that Cd in liver is positively linked to the age of the fish. In this context, some authors[46] stated that Cd concentrations in the liver of king mackerel, *Scomberomorus cavalla* increased with increasing fork length. Furthermore, some reported[67] recorded Cd concentrations in the liver of *Swordfish, Xiphias gladius* up to 46.9 mg/g wet wt. It is suggested that benthic fish are likely to have higher heavy metal concentrations than fish inhabiting the upper water column because they are in direct contact with the sediments and their greater uptake of heavy metal concentrations from zoo benthic predators[68]. However, results from several studies did not support this suggestion or even contradict it; others[49] found that *Cynoglossus gracilis* had the lowest level of metal accumulation among investigated species despite that it is a typical benthic fish. Also, some researchers[69] did not find segregation between pelagic and benthic fish in their accumulation of metals in the liver and kidneys. Results of the present study provide weak or no support for this suggestion, where variations between pelagic and benthic organisms were detected only as high concentration of Fe in the gill of the benthic fish when compared to other species. This finding may be attributed to higher levels of Fe in subsurface water of the Red Sea[70]. Although fish are mostly migratory and seldom settle in one place, metal accumulation in fish organs provides evidences of exposure to contaminated aquatic environment[54] and could be used to assess the health condition of the area from which they were collected. In the present study, spatial distribution of metals showed significant high concentrations of Cu, Zn, Pb, Cd and Mn in Gulf. Also, the results from different species showed that, pelagic fish (*Euthynnus affinis, Trachurus indicus*, *Scomber japonicus, Pomadasys stridens)* recorded significantly the highest concentration of Cd in muscle, and relatively high Cd concentrations in liver and high accumulation of Al, Ni, V, Mg, Ca, Sr in gill. These results agree with the previous studies that reported high metal levels in the water of

Suez Bay when compared to those from the Red Sea proper[71,72], which is mainly due to the industrial and anthropogenic input of metals from Suez city and the maritime activities through the Suez Canal.

Health-Risk Assessment for Fish Consumption

It is well known that muscles are not an active site for metal biotransformation and accumulation[7]. But in polluted aquatic habitats the concentration of metals in fish muscle may exceed the permissible limits for human consumption and imply severe health threats. To keep public health risk of the Suez Gulf fish consumption, we compared metal levels in muscle of the current study **Table (2**) with the maximum permissible limits for human consumption (MPL) established by many different organizations, as well as comparing metal concentrations in muscle to those reported in fish species from the previous studies **Table (3).** The results obtained for muscle samples were compared with limit values and guidelines found in the bibliography using wet weights. The levels of Cu, Zn, Fe, Mn, Co, Ni and Cr determined in the muscle of the ten studied fish species were lower than the maximum levels and guidelines values described in the literature **Table (3**). On the other hand, the maximum level of Pb and Cd in this study was 0.1340 and 0.4095 µg /g wet wt, respectively. These levels were higher than the limit values for fish proposed by international standards and guidelines[43,38,39] in *Sauridaundo squamous* and *Rhabdosargus haffar*a. Although, such high levels were detected in *Sauridaundo squamous* and *Rhabdosargus haffar*a**,** we cannot consider that this species is not fit for human consumption because (as illustrated below) large quantities (1865; 170 g) **Table (5)** of this fish species has to be eaten daily by a person to be affecting the human health. The results in previous literatures were somewhat closer to or higher than our obtained data for similar fish species. For example some reported[26,72] recoded that the metal levels of Cd, Pb, Cu, Fe, Mn and Zn in muscle of *Nemipterus japonicus, Trachurus species* from Hurghada and Suez Gulf **Table (3),** were closer to those recorded in the same species of the current work. In addition, metal levels in the present study were generally lower or within the ranges of those found in the fish of the Red Sea and Suez Bay[9,29,32,15,24,35]. After all, fish in Suez Gulf were found to be safe for consumption and do not pose a significant threat to the health of human consumers.

Daily Consumption Safety

As consumption of fish is a possible source of metal accumulation in humans, there is great interest in estimation of the daily intakes of heavy metals through fish consumption. The estimated daily intakes (EDI) of heavy metals (µg/day/person) through consumption of economically important fish species by Egyptian people in the Suez City is illustrated in **Table (5)**. According to the Directorate General of Fisheries in Egyptian Ministry of agriculture, the average quantity of fish consumed per Egyptian person (assuming average body weight of 70-kg must consume 54.795g/day in Egypt[73]. Multiplying this value by the concentration of each metal in analyzed fish **Table (2),** the average daily intake of metals per person can be estimated. Daily intake of heavy metals was estimated on the basis of the concentrations measured in fish muscle and daily fish consumption rate (54.795 g). Average Egyptian body weight was assumed to be 70 kg. A current metal intake was compared with the respective permissible tolerable daily intake for a 70 kg person (PTDI70) (µg/day). The values of estimated daily intakes (EDI) of Cu, Zn, Mn, Ni, Cd and Pb in muscle of fish, in this study, are well below their corresponding permissible tolerable daily intake for 70 kg person (PTDI70) values **Table (5)**. The dose of a toxic metal that one obtains from fish however, not only depends on the concentration of specific metal in fish, but also on the quantity of fish (intake) consumed. As high intakes of fish are traditional components of the diet of some Egyptian people, we also calculated the daily amount (in grams) of each fish species that should be consumed in order to attain the permissible tolerable daily intake of metal for 70 kg person, PTDI70 **Table (5).** Accordingly, Egyptian person will be at risk of the deleterious effects of a metal only if the daily intake of any fish species included in the study exceeded their respective PTDI70. Considering normal consuming habits, we can firmly state that the calculated daily intake of fish is far away from the actual daily amount of fish consumed by most Egyptian people in general **Table (5**) and therefore, no risk of normal fish consumption originating from the Suez Gulf on Egyptian people's health. Although level of heavy metals is not high, care must be taken considering consumption of large quantities of fish. It is also recommended to conduct continuous monitoring for fish species in Suez Gulf to ensure that the concentrations of metals remain within the prescribed worldwide limits.

Table 5: The estimated daily intakes (EDI) of heavy metals (μg/day/person) through consumption of economically important fish species by adult people (assuming 70 kg person)

Heavy metals	Cu	Pb	**Co**	Ni	Mn	Cd	Fe	Zn
Fish species								
Sauridaundo squamis	10.128 (189,393)^{c}	7.340 (1865)^{c}	**N.D** (**N.D**)^{c}	8.020 (2390)^{c}	18.625 (66,939)^{c}	3.059 (1554)^{c}	540.400 (5678)^{c}	343.104 (11178)^{c}
Euthynnus affinis	119.804 (16,025)^{c}	4.246 (3225)^{c}	**N.D** (**N.D**)^{c}	4.984 (2747)^{c}	11.691 (45,923)^{c}	4.430 (866)^{c}	1848.46 (1660)^{c}	521.626 (7352)^{c}
Rhabdosargus haffara	16.144 (2946)^{c}	3.339 (4091)^{c}	0.667 (**N.D**)^{c}	8.431 (2274)^{c}	21.995 (24,414)^{c}	22.439 (170)^{c}	516.415 (5942)^{c}	402.316 (9534)^{c}
Argyrops spinifer	17.195 (111,536)^{c}	3.348 (4091)^{c}	N.D (**N.D**)^{c}	5.145 (3727)^{c}	16.817 (31,932)^{c}	2.047 (1871)^{c}	2795.055 (1097)^{c}	250.917 (15287)^{c}
Nemipterus japonicus	21.682 (88,450)^{c}	0.819 (16,778)^{c}	N.D (**N.D**)^{c}	2.525 (7592)^{c}	31.036 (17,302)^{c}	14.458 (265)^{c}	929.383 (3301)^{c}	298.918 (12832)^{c}
Oreochromis niloticus	63.831 (30,042)^{c}	1.174 (11,682)^{c}	N.D (**N.D**)^{c}	7.399 (2592)^{c}	22.077 (24,323)^{c}	0.587 (6542)^{c}	726.269 (4225)^{c}	519.818 (7378)^{c}
Trachurus indicus	72.412 (26,475)^{c}	2.778 (4930)^{c}	0.883 (**N.D**)^{c}	8.004 (2396)^{c}	11.038 (48,659)^{c}	2.208 (1736)^{c}	832.857 (3684)^{c}	320.863 (11953)^{c}
Peneus japonicas	0.332 (573,7704)^{c}	0.912 (15,060)^{c}	N.D (**N.D**)^{c}	3.444 (5564)^{c}	13.397 (40081)^{c}	5.972 (642)^{c}	267.389 (11475)^{c}	384.842 (9967)^{c}
Scomber japonicus	37.825 (50,702)^{c}	0.947 (14,450)^{c}	N.D (**N.D**)^{c}	6.330 (3030)^{c}	2.610 (205,882)^{c}	2.111 (1818)^{c}	456.645 (671)^{c}	374.288 (10237)^{c}
Pomadasys stridens	27.091 (70,792)^{c}	3.074 (4098)^{c}	0.898 (**N.D**)^{c}	3.197 (6003)^{c}	16.767 (32026)^{c}	4.601 (833)^{c}	519.473 (5907)^{c}	262.523 (14610)^{c}
PTDI^{a}	**500**	**3.57**	**--**	**5.0**	**140**	**1.0**	**800**	**1,000**
PTDI^{b}70	**35,000**	**250**	**--**	**350**	**9,800**	**70**	**56,000**	**70,000**

N.D: Under the limit of detection; ^{a}**PTDI:** provisional permissible tolerable daily intake (μg /kg body weight/day), calculated from provisional permissible tolerable weekly. Intake **(PTWI)** cited in[33,42]

^{b}**PTDI70:** permissible tolerable daily intake for 70 kg person (μg /day) =PTDI x70 kg.^{c} **Values between brackets** are the daily intake (**in grams)** of each fish species that should be consumed in order to attain the permissible tolerable daily intake of metal for 70 kg person (=PTDI70 (μg /day) **/** metal concentration (μg /g)[42]**.**

CONCLUSION

Metal concentrations in ten fish species were within the same range or below the concentrations in some species from previous studies.

The results also showed that metal accumulation varied between organs and species depending on species specific factors like feeding behavior, swimming patterns and genetic tendency, and/or other factors like age and geographical distribution that caused variation in metals accumulations between fish from different species.

Health risk analysis of heavy metals in the edible parts of the fish indicated safe levels for human consumption and concentrations in the muscles are generally accepted by the international legislation limits. Lead and cadmium concentrations however, exceeded the permissible limits in fish proposed by EU limits in *Sauridaundo squamous* and in *Rhabdosargus haffara* by both European Commission (EC) and England. The heavy metal concentrations in most fishes were well below the limits proposed for fish by various international standards and guidelines[43,42,39], Turkish guidelines and Saudi guidelines. Regarding the daily intake and safety aspects, the examined fish were safe for human consumption at least with regard to residual levels of cadmium, copper, manganese, nickel, lead and zinc but a continuous monitoring of heavy metals in Suez Gulf is necessary to insure the prescribed worldwide limit.

REFERENCES

1. Medeiros R., dos Santos L., Freire A., Santelli R., Braga A., and Krauss T., Determination of inorganic trace elements in edible marine fish from Rio de Janeiro State, Brazil, Food Control, 23, 2012, 535-41.
2. Kris-Etherton P., Harris W., and Apple L., Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease, Circulation, 106, 2002, 2747-57.
3. Yilmaz F., Ozdemir N., Demirak A., and Tuna A., Heavy metal levels in two fish species Leuciscus cephalus and Lepomis gibbosus, Food Chem, 100, 2007, 830-5.
4. Castro G. M., and Mendez A. M., Heavy metals: implications associated to fish consumption, Environ Toxicol Pharmacology, 26, 2008, 263-71.
5. Al-Busaidi M., Yesudhason P., Al-Mughairi S., Al-Rahbi W., Al-Harthy K., and Al-Mazrooei N., Toxic metals in commercial marine fish in Oman with reference to national and international standards, Chemosphere, 85(1), 2011, 67-73.
6. Meche A., Martins M., Lofrano B., Hardaway C., Merchant M., and Verdade L., Determination of heavy metals by inductively coupled plasma-optical emission spectrometry in fish from the Piracicaba River in Southern Brazil, Microchem J., 94, 2010, 171-4.
7. Elnabris K., Muzyed S., and El-Ashgar N., Heavy metal concentrations in some commercially important fishes and their contribution to heavy metals exposure in Palestinian people of Gaza Strip (Palestine), J Assoc Arab Univ Basic Appl Sci., 13, 2013, 44-51.
8. Mustafa C., and Guluzar A., The relationships between heavy metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six Mediterranean fish species. Environ Pollut, 121, 2003, 129-36.
9. Hanna R., Levels of heavy metals in some Red Sea fish before Hot Brine pools' mining, Mar Pollut Bull., 20, 1989, 631-5.
10. Ameir N. M., Physico-chemical studies of some pollutants in the light of environmental assessments, M.Sc. Thesis, Faculty of Science, (Girls), Al-Azhar University, 2005.
11. EL-Moselhy K. M., Accumulation of copper; zinc; cadmium and lead in some fish from the Gulf of Suez, Egypt, J Aquat Biol Fish, 3(1), 2000, 73-83, 235-249.
12. REMIP WORKING GROUPs 2(WG2), JICA and EEAA, State oil pollution and Management in Suez Gulf region, 15, 2008.
13. Shakweer L., Effect of waste disposal on the chemical composition of some aquatic organisms' long Alexandria coastal waters, Ph.D. thesis faculty of science AL-Azhar University, Egypt, 1993, 64-66.
14. Patnaik P., Handbook of environmental analysis chemical pollution in air, water soil and solid wastes Lewis, publishers, BOCA. Raton, New York Landon, Tokyo, 1997, 187-192.
15. Abdallah M., Trace element levels in some commercially valuable fish species from coastal waters of Mediterranean Sea, Egypt. J Mar Syst., 73, 2008, 114-22.
16. Homira A., Martine L., Marc E. S., Mohamad R., and Fatemi W. B., Accumulation of trace metals in the muscle and liver tissues of five fish species from the Persian Gulf. Environ Monit Assess, 157, 2009, 499–514.
17. Khaled A., Seasonal determination of some heavy metals in muscle tissues of Siganus rivulatus and Sargus sargus fish from El-Mex Bay and Eastern Harbor, Alexandria, Egypt, Egypt J. Aquat Biol Fish, 8(1), 2004, 65-81.
18. Amal H., and Azza K., Determination of metals in tuna species and bivalves from Alexandria, Egypt, Egyptian Journal of Aquatic Research, 40, 2014, 9–17.
19. Chi Q.Q., Zhu G.W., and Alan L., Bioaccumulation of heavy metals in fishes from Taihu Lake, China, Journal of Environmental Sciences, 19, 2007, 1500-1504.
20. Tuzen M., Toxic and essential trace elemental contents in fish species from the Black Sea, Turkey, Food Chem. Toxicology, 47, 2009, 1785–1790.
21. Yi Y., Wang Z., Zhang K., Yu G., and Duan, X., Sediment pollution and its effect on fish through food chain in the Yangtze River, Int. J. Sediment Res., 23, 2008, 338–347.
22. Benoit A.L., William E., and Fernand C., Trace metal concentrations in sediments and fish in the vicinity of ash lagoon discharges from coal-combustion plants in New Brunswick and Nova Scotia, Canada. Arch. Environ. Contam. Toxicol, 61, 2011, 472–481.
23. Rejomon G., Nair M., and Joseph G., Trace metal dynamics in fishes from southwest coast of India, Environ. Monit. Assess, 167, 2010, 243–55.

24. El-Moselhy K. M., Response of fish to metal pollution along the Egyptian coast, Ph.D. Thesis. Egypt, Faculty of Science, Tanta Univ, 1996.

25. Ying H., Liang C., Xiaolan Z., Dongping Z., Xinyu Z., Yingxin Y., and Jiamo F., Trace elements in fish from Taihu Lake, China: Levels, associated risks, and trophictransfer, Ecotoxicology and Environmental Safety, 90, 2013, 89–97.

26. Ahmed N., El-Deek M., and Emara H., Heavy metals in the muscle and bone of some fish species from the Red Sea, Special Issue: Symp. Red Sea Mar Environ. J KAU Mar Sci., 7, 1996, 25-31.

27. Kama J. E., Shareef K. M., and Nizam M. E., Heavy metal concentrations in some commercially important fishes and their contribution to heavy metals exposure in Palestinian people of Gaza Strip (Palestine), Journal of the Association of Arab Universities for Basic and Applied Sciences, 13, 2013, 44–51.

28. Nfon E., Cousins I.T., Jarvinen O., Mukherjee A.B., Verta M., and Broman D., Trophodynamics of mercury and other trace elements in a pelagic food chain from the Baltic Sea, Sci. Total Environ., 407, 2009, 6267–6274.

29. Abdelmoneim M., and El-Deek M., Lethrinus family: a model of edible Red Sea fish with low heavy metals accumulation, In: Proceedings of the 2nd Alexandria Conference (Food Sci. Tech.). Egypt: Fac. Agri., Alexandria Univ., March 2-4, 1992, 439-48.

30. Safiur R. M. A., Hossain M., Narottam S., and Atiqur R., Study on heavy metals levels and its risk assessment in some edible fishes from Bangshi River, Savar, Dhaka, Bangladesh. Food Chemistry, 134, 2012, 1847–1854.

31. Abu Hilal A., and Ismail N., Heavy metals in eleven common species of fish from the Gulf of Aqaba, Red Sea. Jordan J Biol Sci., 1(1), 2008, 13-8.

32. Emara H., El-Deek M., and Ahmed N., A comparative study on the levels of trace metals in some Mediterranean and Red Sea fishes, Chem Ecol, 8, 1993, 119-27.

33. Turkmen M., Turkmen A., Akyurt I., and Tepe Y., Limpet, Patella caerulea Linnaeus, 1758 and Barnacle, Balanus sp., as biomonitors of trace metals availabilities in -Iskenderun Bay, Northern East Mediterranean Sea, Bulletin of Environmental Contamination and Toxicology, 74, 2009, 301–307.

34. Ahmad H. A. H., and Naim S. I., Heavy Metals in Eleven Common Species of Fish from the Gulf of Aqaba, Red Sea, Jordan journal of Biological sciences, 1, 2008, 13–18.

35. Ali A.A., Elazein E., and Alian M., Investigation of heavy metals pollution in water, sediment and fish at Red Sea-Jeddah Coast- KSA at two different locations, J Appl Environ Biol Sci., 1(12), 2011, 630-7.

36. Chukwujindu M. A. I., Metal concentrations in selected brands of canned fish in Nigeria: Estimation of dietary intakes and target hazard quotients. Environ Monit. Assess, 2015, 187-85.

37. El-Moselhy K. M., Othman A.I., Abd El-Azem H., and El-Metwally M.E.A., Bio-accumulation of heavy metals in some tissues of fish in the Red Sea, Egypt. Egyptian journal of basic and applied sciences, 1, 2014, 97-105.

38. EC, European Community, Commission Regulation No 78/2005 (pp. L16/43–L16/45), Official Journal of the European Union, (20.1.2005), 2005.

39. MAFF, (Ministry of Agriculture, Fisheries and Food), Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea, 1997, In Aquatic Environment Monitoring Report No. 52, Center for Environment, Fisheries and Aquaculture Science, Lowestoft, UK, 2000.

40. FAO, (Food and Agriculture Organization), Compilation of legal limits for hazardous substances in fish and fishery products. FAO Fishery Circular, 464, 1983, 5-100.

41. Dural M., Goksu M., and Ozak A. A., Investigation of heavy metal levels in economically important fish species captured from the Tuzla lagoon. Food Chem., 102, 2007, 415-21.

42. FAO/WHO, Evaluation of certain food additives and the contaminants mercury, lead and cadmium, WHO Technical Report, Series 505, 1989.

43. EU, Commission Regulation as regards heavy metals, Directive, 2001/22/EC, No. 466, 2001.

44. SASO, Saudi Arabian Standards Organization, Maximum limits of contaminating metallic elements in foods. Riyadh, Saudi Arabia, 1997.

45. Dural M., Goksu A. A., and Ozak B., Derici, Bioaccumulation of some heavy metals in different tissues of Dicentrarchus labrax L, 1758, Sparusaurata L, 1758, and Mugilcephalus L, 1758 from the Camlik Lagoon of the eastern coast of Mediterranean (Turkey). Environ. Monit. Assess., 118, 2006, 65–74.

46. Ploetz D., Fitts B., and Ice T., Differential accumulation of heavy metals in muscle and liver of a marine fish (King Mackerel, Scomberomorus cavalla Cuvier) from the northern Gulf of Mexico. USA, Bull Environ Contam Toxicology, 78, 2007, 134-7.

47. Gorur F., Keser R., Akcay N., and Dizman S., Radioactivity and heavy metal concentrations of some commercial fish species consumed in the Black Sea Region of Turkey. Chemosphere, 87, 2012, 356–61.

48. Amiard J., Amiard T. C., Barka S., Pellerin J., and Rainbow P., Metallothioneins in aquatic invertebrates: their role in metal detoxification and their use as biomarkers. Aquat Toxicol., 76, 2006, 160-202.

49. Zhao S., Feng C., Quan W., Chen X., Niu J., and Shen Z., Role of living environments in the accumulation characteristics of heavy metals in fishes and crabs in the Yangtze River Estuary, China. Mar Pollut Bull., 64, 2012, 1163-71.

50. Dural M., Goksu M., and Ozak A. A., Investigation of heavy metal levels in economically important fish species captured from the Tuzla lagoon. Food Chem., 102, 2007, 415-21.

51. Kargin F., Metal concentrations in tissues of the freshwater fish Capoetabarroisi from the Seyhan River (Turkey). Bull Environ Contam Toxicol., 60, 1998, 822-8.

52. Liu P., Wang C.N., Song X. Y., and Wu Y. N., Dietary intake of lead and cadmium by children and adults—result calculated from dietary recall and available lead/cadmium

level in food in comparison to result from food duplicate diet method. Int. J. Hyg. Environ. Health, 213, 2010, 450–457.

53. Joksimovic D., Tomic I., Stankovic A.R., Jovic M., and Stankovic S., Trace metal concentrations in Mediterranean blue mussel and surface sediments and evaluation of the mussel's quality and possible risks of high human consumption. Food Chem., 127, 2011, 632–637.

54. Qadir A., and Malik R., Heavy metals in eight edible fish species from two polluted tributaries (Aik and Palkhu) of the River Chenab. Pakistan, Biol Trace Elem Res., 143, 2011, 1524-40.

55. Eisler R., Compendium of trace metals and marine biota 2, Amsterdam: Vertebrates Elsevier, 2010.

56. AL- Yakoob S., Bou- Olayan A. H., and Bahloul M., Trace metals in Gill of Fish from the Arabian Gulf Bull. Environ. Contam., 53, 1994, 718-725.

57. Dhaneesh K., Gopi M., Ganeshamurthy R., Kumar T., and Balasubramanian, T., Bio-accumulation of metals on reef associated organisms of Lakshadweep Archipelago, Food Chem., 131, 2012, 985-91.

58. Moore J., and Ramamoorthy S., Heavy metals in natural waters, applied monitoring and impact assessment, New York, Springer-Verlag, 1984.

59. Handy R.D., and Eddy F.B., Surface absorption of Aluminum by gill tissue and body mucus of rainbow trout, Salmogairdnerii, at the onset of episodic exposure. J. Fish Biol., 34, 1989, 865–874.

60. Schiffman R.H., A perfusion study of the movement of strontium across the gills of rainbow trout (Salmogairdnerii), Biol. Bull., 1961, 110–117.

61. deVries M.C., Gillanders B.M., and Elsdon T.S., Facilitation of barium uptake into fish otoliths, influence of strontium concentration and salinity, Geochim. Cosmochim. Acta., 69, 2005, 4061–407.

62. Erdogrul O., and Erbilir F., Heavy metal and trace elements in various fish samples from Sir Dam Lake, Kahramanmaraş, Turkey. Environ. Monit. Assess, 130, 2007, 373–379.

63. Uysal K., Emre Y., and Kose E., The determination of heavy metals accumulation ratios in muscle, skin and gills of some migratory fish species by inductively coupled plasma-optical emission spectrometry (ICP-OES) in Beymelek Lagoon (Antalya/ Turkey). Microchem., J. 90, 2008, 67–70.

64. Ray D., Banerjee S., and Chatterjee M., Bioaccumulation of Nickel and Vanadium in tissues of Catfish Clariasbatrachus. J. Inorg.Biorg.Biochem., 38, 1990, 169-173.

65. Veer M., Bhat U., and Shanmukhappa H., Copper, Chromium and manganese in some Fishes of Kali Estuary, Karwa. Fish Technol Soc. Fish Technol Cochin., 27, 1990, 112-114.

66. EPA, Water quality criteria, Washington, DC. Environmental Protection Agency, 1972.

67. Kojadinovic J., Potier M., Le Corre M., Cosson R., and Bustamante P. Bioaccumulation of trace elements in pelagic fish from the western Indian Ocean. Environ Pollut., 146, 2007, 548-66.

68. Yi Y., Yang Z., and Zhang S., Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. Environ Pollut., 159, 2011, 2575-85.

69. Bustamante P., Bocher P., Che-erel Y., Miramand P., and Caurant F., Distribution of trace elements in the tissues of benthic and pelagic fish from the Kerguelen Islands, Sci Total Environ., 313, 2003, 25-39.

70. Shriadah M., Okbah M., and El-Deek M., Trace metals in the water columns of the Red Sea and the Gulf of Aqaba, Egypt. Water Air Soil Pollut., 153, 2004, 115-24.

71. Hamed M., and El-Moselhy K. M., Levels of some metals in coastal water and sediments of the Red Sea, Egypt. J AMSE, 6, (1, 2), 2000, 43-58.

72. El-Moselhy K. M., Studies on the heavy metal level in some economic fishes in the Suez Gulf, M. Sc. Thesis. Egypt, Fac. Sci. Mansoura Univ., 1993.

73. www.akhbarak.net/news/(2015)/01/04/5627940/articles/17347147.

Source of Support: Nil, **Conflict of Interest:** None.