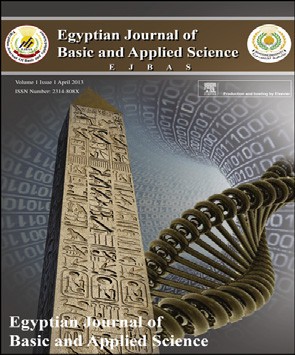
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Full Length Article

Bioaccumulation of heavy metals in some tissues of fish in the Red Sea, Egypt



*Kh. M. El-Moselhy* [*a*](#_bookmark0)*,*\**, A.I. Othman* [*b*](#_bookmark1)*, H. Abd El-Azem* [*a*](#_bookmark0)*,*

*M.E.A. El-Metwally* [*a*](#_bookmark0)

a *Marine Pollution Dept., National Institute of Oceanography and Fisheries, Egypt*

b *Zoology Dept, Faculty of Science, El-Mansoura University, Egypt*

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## a b s t r a c t

The concentrations of heavy metals (Cu, Zn, Pb, Cd, Fe and Mn) were measured in the liver, gills and muscles of fourteen benthic and pelagic fish species collected from three main landing areas (Shalateen, Hurghada and Suez) in the Egyptian Red Sea. The levels of heavy metals varied significantly among fish species and organs. As expected, muscles always possessed the lowest concentrations of all metals. In most studied fish, the liver was the target organ for Cu, Zn and Fe accumulation. Pb and Mn, however, exhibited their highest concentrations in the gills. Different species of fish showed inter-specific variation of metals, as well as variations between fish from the same species. These differences were discussed for the contribution of potential factors that affected metals' uptake, like age, geographical distribution and species' specific factors. Generally, recorded metal concen- trations were within the range or below the levels in similar species from global studies.

The concentration of metals in the present fish muscles were accepted by the international legislation limits and are safe for human consumption.

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# 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]](#_bookmark8). The American Heart Association recommended eating fish at least twice per weak in order to reach the daily intake of omega-3 fatty acids [[2]](#_bookmark9).

\* *Corresponding author*.

E-mail addresses: [khalidelmoselhy@yahoo.com](mailto:khalid_elmoselhy@yahoo.com), [khalid\_elmoselhy@yahoo.com](mailto:khalid_elmoselhy@yahoo.com) (Kh.M. El-Moselhy).

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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 [[3,4]](#_bookmark10). The con- tent of toxic heavy metals in fish can counteract their bene- ficial effects; several adverse effects of heavy metals to human health have been known for long time [[5]](#_bookmark12). This may include serious threats like renal failure, liver damage, cardiovascular diseases and even death [[6,7]](#_bookmark13). 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 [[8]](#_bookmark14).

In the last few decades, the concentrations of heavy metals in fish have been extensively studied in different parts of the world [[9]](#_bookmark15). Most of these studies concentrated mainly on the heavy metals in the edible part (fish 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 (i.e., geographical location) [[4,10]](#_bookmark11).

Red Sea is a semi-enclosed tropical body of water. It has been considered to be a relatively unpolluted marine envi- ronment. In the last few decades, however, evidence of heavy metal pollution has been found in various locations [[12]](#_bookmark17). 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.

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 [[13](#_bookmark18)e[20]](#_bookmark18). However due to increasing anthropogenic and industrial stress on the Red Sea, continuous monitoring of the environmental conditions of the Red Sea is required.

In the present study, levels of heavy metals in the organs of some commercial fish from landing areas on the Egyptian Red Sea were determined, aiming to evaluate the current envi- ronmental status of this broad section of the Red Sea. Also metals' content in muscles were compared against the rec-

ommended maximum permissible limit (MPL) to assess the

quality of fish for human consumption.

# Materials and methods

### *Fish sampling*

Fourteen commercial fish species were purchased from local fishermen at three main fish landing areas on the Red Sea: Shalateen, Hurghada and Suez ([Fig. 1](#_bookmark2)) during December 2010 and January 2011. The collected species were: *Epinephelus* sp., *Caranx* sp., *Scarus gibbus*, *Nemipterus japonicus*, *Sardinella* sp., *Synodus* sp., *Carangoides bajad*, *Lutjanus bohar*, *Thunnus*

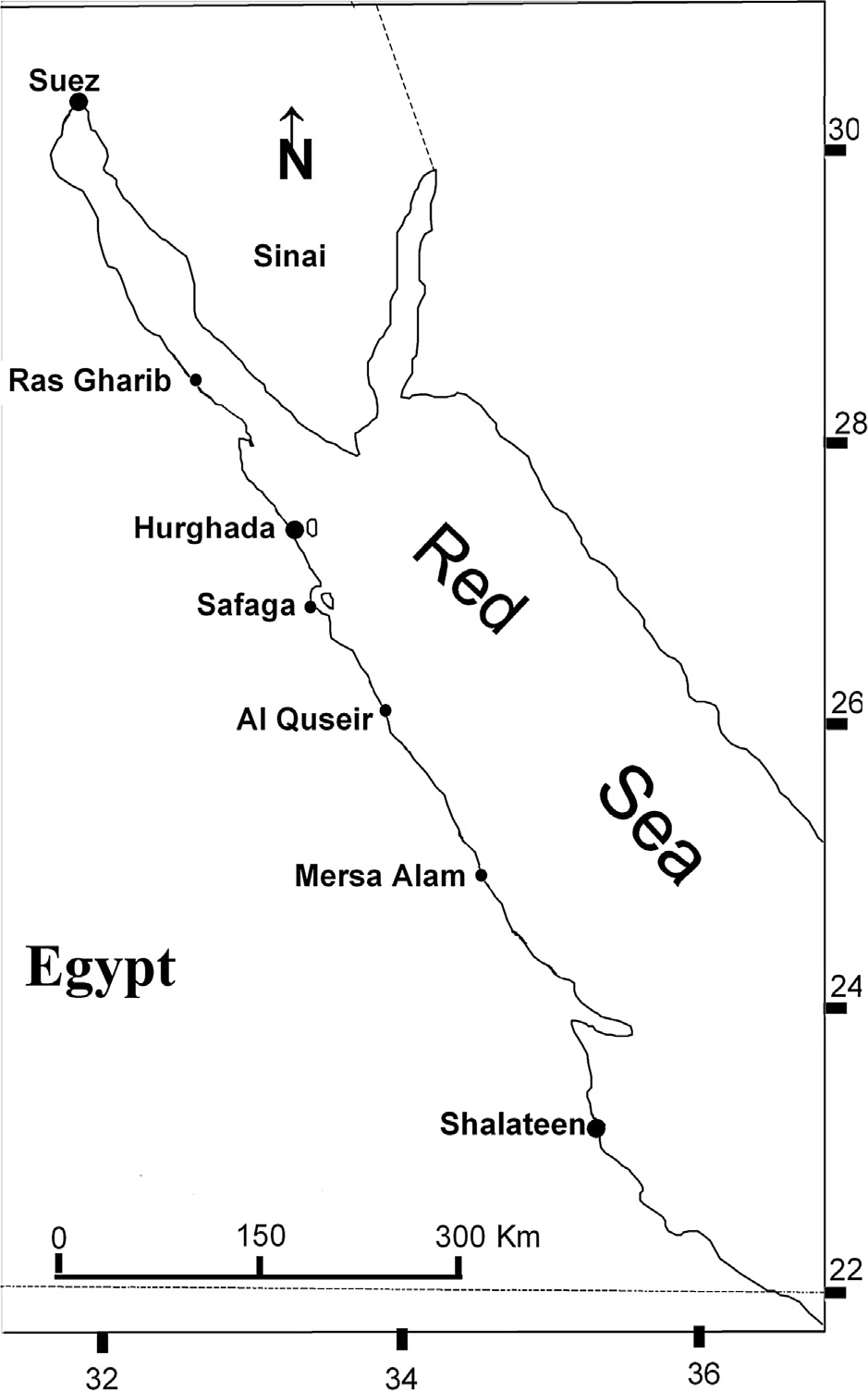


Fig. 1 e Red Sea map showing the sites of sampling.

*albacares*, *Gerres oyena*, *Sargocentron spiniferum*, *Siganus rivula- tus*, *Lethrinus* sp. and *Trachurus mediterraneus*. These fish spe- cies represent different biotops and are economically important ([Table 1](#_bookmark3)).

Collected fish were immediately preserved in an ice box and transferred to the laboratory where they were classified, weighed, measured by total length and kept frozen at —20 ◦C until further analysis.

### *Determination of metal concentrations*

Preparation of subsamples and analysis were made according to FAO Technical Paper No. 212 [[21]](#_bookmark23). For metal analysis, frozen fish were partially thawed, and each fish was dissected using stainless steel instruments. Muscles, liver and gills were taken out; composite samples of 2e5 g were used for subsequent analysis.

The samples were digested with ultra pure nitric acid (and perchloric acid for gills 4:1) at 100 ◦C until the solution become clear. The solution was made up to known volume with deionized distilled water and analyzed for Cu, Zn, Pb, Cd, Fe and Mn using the Atomic Absorption Spectrophotometer (AAS model GPC A932 ver. 1.1). The obtained results were expressed as mg/g wet weight.

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All reagents were of analytical grade; glassware were soaked in 10% nitric acid and later rinsed with distilled water prior to use in order to avoid metal contamination.

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| Table 1 e The ecological characteristics and recorded morphometric measures of examined fish species. |
| Scientific name English name Feeding habits Biotype complex No. of Length Weight  samples (cm) (g) |
| Shalateen *Epinephelus* sp. Grouper Predatory, Carnivore (small fish and Reef-associated 5 27e35 259e680  benthic invertebrates)  *Caranx* sp. Trevally Carnivore (fish and invertebrates) Plagic 1 87.5 24,500  *Scarus gibbus* Parrotfish Herbivore (on algae) Pelagic 4 34.1e37.6 450e555  (Reef-associated)  *Synodus* sp. Lizard fish Carnivore (small fish) Demersal 10 16.5e20.1 32e51  (benthic)  *Nemipterus japonicus* Threadfine bream Carnivore (small fish, invertebrates Demersal 10 14.5e19.1 33e69  polychates)  *Carangoides bajad* Gold-spotted trevally Carnivore (fish and crusteceans) Plagic 1 33.50 496.00  *Lutjanus bohar* Snappers Canivore (fish and invertebrates) Plagic 4 32e36 456e635  (Reef-associated)  *Thunnus albacares* yellowfin tuna Carnivore (fish and invertebrates) Plagic 4 39e50 448e7500  *Gerres oyena* Silver biddy Carnivore (small invertebrates living Demersal 5 17.5e24.7 58e168  on sandy bottoms)  *Sargocentron* Squirrelfish Carnivore (on small crusteceans) Plagic 5 17.9e29 83.5e413  *spiniferum* (Reef-associated)  Hurghada *Epinephelus* sp. Grouper Predatory, Carnivore (small fish and Reef-associated 4 32e34.8 543e650  benthic invertebrates)  *Caranx* sp. Trevally Carnivore (fish and invertebrates) Plagic 1 39.6 6250  *Scarus gibbus* parrotfish herbivore (on algae) Pelagic 4 26.20e33.6 315e486  (Reef-associated)  *Sardinella* sp. Sardinella Filter feeders on phytoplankton and Plagic 8 20.1e25 69e142  zooplankton  *Siganus rivulatus* Marbled Spinefoot Herbivore Demersal 10 18.2e20.1 68e105 (Reef-associated)  Suez *Epinephelus* sp. Grouper Predatory, Carnivore (small fish and Reef-associated 4 23e24.5 156.3e189  benthic invertebrates)  *Synodus synodus* Lizard fish Carnivore (small fish) Demersal 10 16e17 22.2e34  (benthic)  *Nemipterus japonicus* Threadfine bream Carnivore (small fish, invertebrates Demersal 10 16e19 59.5e89.5  polychates)  *Sardinella* sp. Sardinella Filter feeders on phytoplankton Plagic 10 13e15.5 17.3e31.5  and zooplankton  *Trachurus* horse mackerel Carnivore (invertebrates and fish) Plagic 10 14.5e18 26.9e43.7  *mediterraneus*  *Lethrinus* sp. Emperor Carvivore (echinoderms, mollusks Plagic 4 21e28 138e257  and crustaceans) (Reef-associated) |

Accuracy and precision were verified by using reference materials (MA-A-2/TM) provided by the International Atomic Agency (IAEA). Analytical results of the quality control sam- ples indicated a satisfactory performance of heavy metal determination within the range of certified values 95e111% recovery for the metals studied.

### *Statistical analysis*

Three-way analysis of variance (ANOVA) was used to indicate significant differences in metal levels among sites, species and organs. And one-way (ANOVA) was used to compare metals between species in single organ (significant values, *p* ≤ 0.05). All data were checked, beforehand, for the homo- geneity of variances and normality; the data which were not normally distributed or not homogeneous were transformed. ANOVA was followed by Duncan's multiple range test to

determine the position of the variance. All statistical calcu-

lations were carried out with SPSS 18.0 for Windows.

# Results

Concentrations of heavy metals (Cu, Zn, Pb, Cd, Fe and Mn) in the muscles, liver and gills of fish collected from landing sites (Shalateen, Hurghada and Suez) on the Red Sea are given in [Tables 2](#_bookmark4)e[4](#_bookmark4), respectively. Accumulation patterns of all metals were significantly different (*p* < 0.001) between the different species, organs and sites (except for Fe) ([Table 5](#_bookmark5)).

As shown in [Tables 2](#_bookmark4)e[4](#_bookmark4), all fish contained the lowest concentrations of metals in muscles, while almost all fish species showed the highest concentrations of Cu, Zn and Fe in the liver, and the highest concentrations of Pb and Mn in the gills. For Cd, the highest concentrations fluctuated between the liver in some species and gills in others. Duncan's multiple

range test indicated variations of metals as the highest levels

of Cu, Zn, Cd and Fe in the liver and the highest Pb and Mn in the gills; while muscles significantly possessed lowest con- centration of all metals.

Regarding the geographical variation of metals, there was no consistent increase of metals in all fish species from one site. However, statistically, Suez showed significantly high

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| Table 2 e Mean (±SD) concentrations of heavy metals (mg/g wet weight) in some organs of fish species collected from Shalateen. |
| CuC ZnB PbB CdB Fe MnB |
| *Epinephelus* sp. Muscle 0.29 ± 0.05 2.42 ± 0.22 0.88 ± 0.12a 0.12 ± 0.02 3.35 ± 0.79 0.15 ± 0.04  Liver 9.60 ± 2.33 59.89 ± 10.02ab 3.08 ± 0.78a 0.86 ± 0.15 291.76 ± 47.60 1.02 ± 0.40  Gills 1.88 ± 0.32 29.00 ± 1.24 4.86 ± 1.82 0.75 ± 0.24 44.52 ± 8.05 1.73 ± 0.14  *Caranx* sp. Muscle 0.36 ± 0.02 2.88 ± 0.11 0.28 ± 0.05 0.07 ± 0.01 7.12 ± 0.74 0.16 ± 0.02  Liver 2.93 ± 0.18 27.30 ± 1.51 0.48 ± 0.11 8.37 ± 0.32a 71.93 ± 8.35 0.97 ± 0.04  Gills 1.36 ± 0.05 15.10 ± 1.49 1.92 ± 0.20 0.32 ± 0.04 46.05 ± 5.17 1.94 ± 0.49  *Scarus gibbus* Muscle 0.30 ± 0.06 *1*.*17* ± *0*.*63x 0*.*21* ± *0*.*09 x* 0.03 ± 0.01 2.07 ± 0.42 0.12 ± 0.02  Liver *0*.*76* ± *0*.*13 x 1*.*76* ± *0*.*33 x 0*.*14* ± *0*.*15 x 0*.*03* ± *0.02 x* 45.05 ± 6.61 *0.17* ± *0.02 x*  Gills 2.26 ± 0.55 *7*.*77* ± *1*.*18 x* 1.54 ± 0.59 0.27 ± 0.08 58.59 ± 10.89 8.80 ± 2.35  *Synodus* sp. Muscle 0.22 ± 0.06 1.92 ± 0.45 0.51 ± 0.14 0.07 ± 0.02 2.81 ± 0.34 0.24 ± 0.08  Liver 4.65 ± 1.22 29.31 ± 2.99 1.00 ± 0.11 0.34 ± 0.24 142.46 ± 7.23 0.86 ± 0.19  Gills 2.97 ± 0.28a 42.87 ± 6.98b 6.93 ± 1.40a 1.15 ± 0.14 324.40 ± 46.25a 15.54 ± 4.27b  *Nemipterus japonicus* Muscle 0.29 ± 0.04 2.22 ± 0.21 0.46 ± 0.15 0.06 ± 0.02 2.21 ± 0.87 0.12 ± 0.03  Liver 2.15 ± 0.29 42.50 ± 10.08 0.17 ± 0.02 0.40 ± 0.15 74.99 ± 18.64 1.12 ± 0.14  Gills 1.68 ± 0.18 19.78 ± 1.57 2.27 ± 0.65 0.70 ± 0.13 73.61 ± 8.09 7.98 ± 1.40  *Carangoides bajad* Muscle 0.33 ± 0.04 3.08 ± 0.77 0.52 ± 0.27 0.08 ± 0.04 3.10 ± 0.12 0.13 ± 0.03  Liver 3.09 ± 0.61 27.49 ± 0.56 1.64 ± 0.15 0.78 ± 0.04 335.47 ± 45.51 0.94 ± 0.03  Gills 2.27 ± 0.24 24.77 ± 2.92 4.46 ± 1.17 0.70 ± 0.09 61.74 ± 3.08 3.72 ± 0.42  *Lutjanus bohar* Muscle 0.24 ± 0.11 2.08 ± 0.28 0.51 ± 0.05 0.03 ± 0.02 2.05 ± 0.26 0.10 ± 0.03  Liver 4.41 ± 0.36 36.02 ± 0.26 0.83 ± 0.03 0.86 ± 0.01 322.55 ± 58.10 1.29 ± 0.12  Gills 2.50 ± 0.16 25.45 ± 2.31 2.30 ± 0.45 0.59 ± 0.05 44.18 ± 9.17 1.43 ± 0.08  *Thunnus albacares* Muscle 0.35 ± 0.06 1.99 ± 0.33 0.32 ± 0.03 0.06 ± 0.01 2.93 ± 0.98 0.11 ± 0.02  Liver 5.61 ± 0.85 24.54 ± 3.16 0.63 ± 0.10 0.40 ± 0.02 224.43 ± 32.68 0.77 ± 0.29  Gills 1.71 ± 0.04 33.41 ± 3.48 2.61 ± 0.33 0.51 ± 0.06 69.65 ± 10.06 5.88 ± 0.78  *Gerres oyena* Muscle 0.31 ± 0.03 12.03 ± 1.72a 0.41 ± 0.11 0.05 ± 0.01 5.73 ± 2.13 0.17 ± 0.06  Liver 2.53 ± 0.83 27.16 ± 2.73 0.82 ± 0.12 0.31 ± 0.10 282.68 ± 65.45 1.58 ± 0.32  Gills 2.04 ± 0.11 29.36 ± 5.61 2.98 ± 0.84 0.50 ± 0.13 91.52 ± 22.93 4.70 ± 0.14  *Sargocentron spiniferum* Muscle 0.24 ± 0.04 2.43 ± 0.22 0.28 ± 0.07 0.06 ± 0.02 5.48 ± 1.94 0.20 ± 0.08  Liver 3.19 ± 0.96 34.01 ± 3.57 0.19 ± 0.01 0.59 ± 0.06 181.00 ± 12.64 1.40 ± 0.24  Gills 1.45 ± 0.22 21.06 ± 1.82 2.01 ± 0.42 0.51 ± 0.08 50.36 ± 4.88 6.57 ± 1.81 |
| Capital letters indicate significant variations between sites.  Small letters mark significant highest concentrations in different species from the three sites. x is the lowest metal concentration in different species. |

concentrations of metals (Cu, Zn, Pb, Cd and Mn) when compared to other sites ([Table 5](#_bookmark5)).

The accumulation of metals in a single species showed significant inter-specific variations in all metals. However it

can be noticed that, different organs exhibited different pat- terns in metals accumulation. In other words, no single type of fish showed the highest metals in all organs (except Mn in *Sardinella* sp.). Therefore, concentrations of metals between

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| Table 3 e Mean (±SD) concentrations of heavy metals (mg/g wet weight) in some organs of fish species collected from Hurghada. |
| CuB ZnB PbC CdC Fe MnB |
| *Epinephelus* sp. Muscle 0.21 ± 0.07 3.00 ± 0.43 0.45 ± 0.09 0.05 ± 0.01 2.96 ± 0.38 0.17 ± 0.04  Liver 8.79 ± 2.70 34.63 ± 4.86 1.16 ± 0.49 0.24 ± 0.03 156.78 ± 105.61 0.58 ± 0.20  Gills *1*.*07* ± *0*.*19 x* 20.23 ± 4.78 1.60 ± 0.52 0.33 ± 0.07 *19*.*95* ± *3*.*10 x 1.01* ± *0*.*40 x*  *Caranx* sp. Muscle 0.46 ± 0.01 4.94 ± 2.52 0.25 ± 0.10 0.05 ± 0.02 9.53 ± 2.77 0.13 ± 0.03  Liver 6.23 ± 0.82 37.12 ± 2.23 0.62 ± 0.17 0.40 ± 0.09 184.07 ± 71.46 1.27 ± 0.11  Gills 1.26 ± 0.31 21.96 ± 0.59 2.18 ± 0.43 0.38 ± 0.05 67.68 ± 12.41 1.97 ± 0.27  *Scarus gibbus* Muscle 0.37 ± 0.01 2.07 ± 0.09 0.24 ± 0.03 *0.03* ± *0.004 x* 3.04 ± 0.48 0.16 ± 0.02  Liver 2.29 ± 0.11 17.66 ± 0.04 2.02 ± 0.19 0.35 ± 0.04 118.56 ± 3.46 1.06 ± 0.04  Gills 2.38 ± 0.86 11.68 ± 4.51 *1*.*03* ± *0*.*50 x 0*.*19* ± *0*.*06 x* 30.92 ± 10.70 4.63 ± 1.79  *Sardinella* sp. Muscle 0.63 ± 0.10a 6.49 ± 1.83b 0.25 ± 0.08 0.07 ± 0.01 11.53 ± 1.68a 0.29 ± 0.05  Liver 2.81 ± 0.14 22.07 ± 1.39 1.05 ± 0.45 0.42 ± 0.08 189.35 ± 5.24 1.84 ± 0.45b  Gills 1.63 ± 0.15 39.45 ± 12.15 1.46 ± 0.23 0.49 ± 0.09 121.37 ± 20.35 8.37 ± 2.43  *Siganus rivulatus* Muscle 0.35 ± 0.03 3.20 ± 0.67 0.44 ± 0.11 0.05 ± 0.01 9.12 ± 4.45 0.27 ± 0.12  Liver 18.62 ± 2.52a 51.70 ± 15.26 0.64 ± 0.28 1.14 ± 0.48 139.27 ± 19.21 0.80 ± 0.18  Gills 2.55 ± 0.04 23.08 ± 0.92 2.32 ± 0.46 0.52 ± 0.04 117.38 ± 19.05 7.96 ± 2.77 |
| Capital letters indicate significant variations between sites.  Small letters mark significant highest concentrations in different species from the three sites. x is the lowest metal concentration in different species. |

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| Table 4 e Mean (±SD) concentrations of heavy metals (mg/g wet weight) in some organs of fish species collected from Suez. |
| CuA ZnA PbA CdA Fe MnA |
| *Epinephelus* sp. Muscle 0.23 ± 0.01 3.98 ± 0.61 0.43 ± 0.05 0.20 ± 0.06b 2.54 ± 1.29 0.16 ± 0.01  Liver 8.51 ± 1.13 64.61 ± 6.46a 1.45 ± 0.20 1.68 ± 0.45 418.64 ± 37.42 1.16 ± 0.04  Gills 2.32 ± 0.35 29.29 ± 4.20 4.86 ± 1.45 1.33 ± 0.26b 27.04 ± 3.93 6.29 ± 1.42  *Synodus* sp. Muscle *0*.*17* ± *0*.*02 x* 3.71 ± 0.10 0.28 ± 0.09 0.04 ± 0.01 1.61 ± 0.54 0.23 ± 0.03  Liver 8.00 ± 2.78 37.91 ± 1.95 1.60 ± 0.52 0.19 ± 0.01 *34*.*75* ± *3*.*34 x* 0.81 ± 0.16  Gills 1.67 ± 0.23 34.04 ± 6.72 3.24 ± 0.12 0.40 ± 0.03 241.47 ± 96.20b 8.94 ± 2.27  *Nemipterus japonicus* Muscle 0.20 ± 0.09 2.70 ± 0.09 0.28 ± 0.01 0.04 ± 0.01 *1.15* ± *0.23* 0.11 ± 0.01  Liver 17.54 ± 5.42a 60.90 ± 15.76ab 0.39 ± 0.08 0.15 ± 0.03 83.64 ± 48.54 0.75 ± 0.27  Gills 1.32 ± 0.11 23.32 ± 2.30 2.36 ± 0.43 0.34 ± 0.02 68.32 ± 7.99 9.90 ± 2.33  *Sardinella* sp. Muscle 0.74 ± 0.28a 8.23 ± 1.88b 0.50 ± 0.43 0.38 ± 0.29a 10.92 ± 4.11a 0.93 ± 0.19a  Liver 3.94 ± 0.88 25.12 ± 6.57 1.34 ± 0.12 1.98 ± 0.17 225.14 ± 10.71 2.87 ± 0.28a  Gills 2.06 ± 0.15 59.90 ± 2.72a 3.76 ± 1.13 1.68 ± 0.38a 112.52 ± 23.43 33.98 ± 6.25a  *Trachurus mediterraneus* Muscle 0.77 ± 0.14a 4.21 ± 0.19 0.40 ± 0.17 0.20 ± 0.02b 6.25 ± 0.46 0.18 ± 0.02  Liver 4.52 ± 0.28 43.64 ± 3.49 1.59 ± 0.06 1.59 ± 0.37 304.52 ± 146.56 0.94 ± 0.17  Gills 2.26 ± 0.04 39.80 ± 8.16 4.03 ± 1.06 0.56 ± 0.15 168.93 ± 38.69 6.31 ± 0.50  *Lethrinus* sp. Muscle 0.25 ± 0.07 3.41 ± 0.69 0.25 ± 0.07 0.23 ± 0.06b 3.03 ± 0.38 *0.10* ± *0.03 x*  Liver 7.63 ± 0.91 52.94 ± 7.70 1.09 ± 0.84 1.44 ± 0.10 656.98 ± 60.13a 1.29 ± 0.27  Gills 1.99 ± 0.94 21.43 ± 3.61 3.09 ± 0.79 1.00 ± 0.31 41.80 ± 12.69 3.17 ± 0.07 |
| Capital letters indicate significant variations between sites.  Small letters mark significant highest concentrations in different species from the three sites. x is the lowest metal concentration in different species. |

species were analyzed in single organ; all results showed significant variations between species. Furthermore, some fish from the same species collected from different sites also significantly accumulated different concentrations of metals (ANOVA: *p* < 0.001 in all cases). Variations of metals distribu-

tion in the studied fish can be summarized as the following:

### *Copper (Cu)*

In the liver, the herbivore *S*. *rivulatus* accumulated the highest concentration of Cu (18.62 ± 2.52 mg/g wet wt); while another herbivore species (*S*. *gibbus*) showed the lowest values (0.76 ± 0.13 mg/g wet wt). Gills showed a narrow range of Cu levels and recorded concentrations from 1.07 ± 0.19 (*Epi- nephelus* sp., Hurghada) to 2.97 ± 0.28 mg/g wet wt *(Synodus* sp., Shalateen). Concentrations of Cu in muscles ranged from

0.17 ± 0.02 *(Synodus* sp., Suez) to 0.77 ± 0.14 mg/g wet wt (*T*.

*mediterraneus*, Suez).

### *Zinc (Zn)*

*Epinephelus* sp. exhibited a tendency to accumulated high concentration of Zn in the liver when compared to other species (64.61 ± 6.46 mg/g wet wt in Shalateen). *Sardinella* sp.

recorded the highest concentrations of Zn in gills (59.90 ± 2.72 mg/g wet wt in Suez), while the highest concen- trations of Zn in muscles were recorded in *G*. *oyena* (12.03 ± 1.72 mg/g wet wt). On the other hand, the herbivore *S*. *gibbus* (from Shalateen) recorded the lowest Zn concentra-

tions in all studied organs (1.76 ± 0.33, 7.77 ± 1.18 and

1.17 ± 0.63 mg/g wet wt in the liver, gills and muscles respectively).

### *Lead (Pb)*

Concentrations of Pb in gills ranged from 1.03 ± 0.5 (*S*. *gibbus*, Hurghada) to 6.93 ± 1.40 mg/g wet wt *(Synodus* sp., Shalateen). Liver showed a wide range of Pb levels ranging from 0.14 ± 0.15 (*S*. *gibbus*, Shalateen) to 3.08 ± 0.78 mg/g wet wt (*Epinephelus* sp.,

Shalateen), while the concentrations of Pb in muscles ranged from 0.21 ± 0.09 (*S*. *gibbus*, Shalateen) to 0.88 ± 0.12 mg/g wet wt *(Epinephelus* sp., Shalateen).

### *Cadmium (Cd)*

Liver showed a wide range of Cd concentrations among the studied fish, a very low Cd concentration (0.03 ± 0.02 mg/g wet wt) was recorded in *S*. *gibbus* (from Shalateen), and an

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Table 5 e Three-way ANOVA showing variations in metals between locations, organs and different species. | | | | | | | | | |
| Source | | df | F | *p* | Cd | Source | df | F | *p* |
| Cu | Site | 2 | 27.689 | <0.001 |  | Site | 2 | 542.142 | <0.001 |
|  | Species | 13 | 22.027 | <0.001 |  | Species | 13 | 183.981 | <0.001 |
|  | Organ | 2 | 596.528 | <0.001 |  | Organ | 2 | 459.103 | <0.001 |
| Zn | Site | 2 | 18.894 | <0.001 | Fe | Site | 2 | 1.087 | 0.34 |
|  | Species | 13 | 17.039 | <0.001 |  | Species | 13 | 20.536 | <0.001 |
|  | Organ | 2 | 803.842 | <0.001 |  | Organ | 2 | 680.953 | <0.001 |
| Pb | Site | 2 | 13.067 | <0.001 | Mn | Site | 2 | 73.435 | <0.001 |
|  | Species | 13 | 14.084 | <0.001 |  | Species | 13 | 45.616 | <0.001 |
|  | Organ | 2 | 314.038 | <0.001 |  | Organ | 2 | 570.757 | <0.001 |

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extremely high concentration (8.37 ± 0.32 mg Cd/g wet wt) was observed in the liver of *Caranx* sp. (Shalateen). In gills, Cd levels varied between 0.19 ± 0.06 (*S*. *gibbus*, Hurghada) and

1.68 ± 0.38 mg/g wet wt (*Sardinella* sp., Suez). Cd concentrations

in the muscles ranged from 0.03 ± 0.01 (*S*. *gibbus*, Shalateen) to

0.38 ± 0.29 mg/g wet wt (*Sardinella* sp., Suez).

### *Iron (Fe)*

In liver, Fe concentrations were found to be between

34.75 ± 3.34 and 656.98 ± 60.13 mg/g wet wt (*Synodus* sp. and *Lethrinus* sp. from Suez, respectively). The concentrations of Fe in gills ranged from 19.95 ± 3.10 (*Epinephelus* sp., Hurghada) to

324.40 ± 46.25 mg/g wet wt (*Synodus* sp., Shalateen). Muscles

recorded Fe concentrations from 1.15 ± 0.23 (*N*. *japonicus*, Suez) to 11.53 ± 1.68 mg/g wet wt (*Sardinella* sp., Hurghada).

### *Manganese (Mn)*

Manganese concentrations in gills showed a wide variation and ranged between 1.01 ± 0.40 (*Epinephelus* sp., Hurghada) and 33.98 ± 6.25 mg/g wet wt (*Sardinella* sp., Suez). In liver, concentrations of Mn ranged from 0.17 ± 0.02 (*S*. *gibbus*, Sha- lateen) to 2.87 ± 0.28 mg/g wet wt (*Sardinella* sp., Suez). Fish muscles recorded the lowest concentrations of Mn and ranged between 0.10 ± 0.03 (*Lethrinus* sp., Suez) and 0.93 ± 0.19 mg/g wet wt (*Sardinella* sp., Suez).

# Discussions

### *Variations in organs ability to accumulate metals*

Fish of the present study always showed the lowest concen- tration of metals in muscle. The essential metals Cu, Zn and Fe were accumulated mainly in the liver, while Pb and Mn exhibited their highest concentrations in gills. The accumu- lation pattern of Cd differed between species where the highest concentrations were fluctuated between the liver and gills.

The accumulation of essential metals in the liver is likely linked to its role in metabolism [[4]](#_bookmark11); high levels of Zn and Cu in hepatic tissues are usually related to a natural binding pro- teins such as metallothioneins (MT) [[27]](#_bookmark29) which act as an essential metal store (i.e., Zn and Cu) to fulfill enzymatic and other metabolic demands [[28,29]](#_bookmark30). In the same way, Fe tends to accumulate in hepatic tissues due to the physiological role of the liver in blood cells and hemoglobin synthesis [[27]](#_bookmark29). On the other hand, the liver also showed high levels of non-essential metals such as Cd; this finding could be explained by the ability of Cd to displace the normally MT-associated essential metals in hepatic tissues [[29]](#_bookmark31). Similar results of high Zn, Cu and Cd in the liver were observed in many field studies [[4,30](#_bookmark11)e[33]](#_bookmark11).

The studied fish tend to accumulate Pb, Mn and to some

extent Cd in gills. Gills are the main route of metal ion ex- change from water [[26]](#_bookmark28) as they have very large surface areas that facilitate rapid diffusion of toxic metals [[25]](#_bookmark27). Therefore, it is suggested that metals accumulated in gills are mainly concentrated from water. This is in agreement with the

findings of Moore and Ramamoorthy [[24]](#_bookmark26). They reported the lack of correlation between Pb residues and feeding habits in aquatic organisms. Similar results for high Pb concentrations in gills were recorded by Kargin [[34]](#_bookmark33), Avenant-Oldewage and Marx [[35]](#_bookmark34), Abu Hilal and Ismail [[37]](#_bookmark36) and Qadir and Malik [[26]](#_bookmark28). Also, Eisler [[30]](#_bookmark32) reported that fish's hard tissues had consis-

tently higher accumulations of Mn than soft tissues.

### *Inter-specific variations in metal accumulation*

Fish in the present study were collected from different habitat and have various morphometric parameters ([Table 1](#_bookmark3)). The present results showed that fish exhibited wide inter-specific variations in metals accumulation in all organs.

Many studies attributed high metal accumulation to the feeding habit of the fish. For instance, Khaled [[23]](#_bookmark25) argued that because *S*. *rivulatus* is an herbivore, it accumulated higher concentrations of metals in their muscles than the carnivore *Sargus sargus*; This suggestion was not a reasonable cause for high metal accumulation in the current study since *S*. *gibbus* (a herbivore) recorded the lowest concentration of metals in most cases during the study, while the other herbivore (*S*. *rivulatus*) showed minor variations (as high concentrations of Cu in liver). Alternatively, Al-Busaidi et al. [[6]](#_bookmark13) suggested that, high Cd concentrations in muscles of yellowfine tuna *T*. *albacares* was 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 except *Epinephelus* sp. which showed a tendency to accumulate metals (Zn, Pb and Cu) in the liver with relatively high concentrations. Apart from previous suggestions, feeding habit may be one reason of metal variation in the filter feeder *Sardinella* sp. which accumulated relatively high con- centrations of all metals except Pb in muscles and exhibited ability to accumulate Mn with high concentrations in all or- gans. These findings in *Sardinella* sp. could be linked to feeding on phytoplankton since it is the most likely biota compart- ment for Zn and Cu concentration [[22,38]](#_bookmark24). Petkevich [[39]](#_bookmark37) also generalized that bony tissues of plankton-feeding fish concentrated manganese to a greater extent than benthos- feeders [[30]](#_bookmark32). Wide agreement with these results in *Sardinella* sp. was observed in the previous studies; Abdallah [[22]](#_bookmark24) recorded high Zn and Pb concentration in the muscles of *sardinella aurita* collected from El-Mex Bay; Alturiqi and Albe- dair [[40]](#_bookmark38) found relatively high concentrations of Zn, Cd, Fe and Mn in sardine collected from the Saudi market in comparison to Grouper and blackspot emperor. Chen and Chen [[41]](#_bookmark39) found that the muscles of *Sardinella lemuru* recorded the highest concentrations of Zn, Fe, Cu, and Mn among nine fish species collected from the Ann-Ping coastal waters, Taiwan.

It was interesting to note that a large fish of *Caranx* sp.

(from Shalateen) showed very high concentrations of Cd in liver (8.37 ± 0.32 mg/g wet wt), which was several times of magnitude greater than other studied fish, even from the

same species ([Tables 2](#_bookmark4)e[4](#_bookmark4)). This finding can be linked to the age of the fish; since Cd is difficult to be excreted from liver once it is accumulated [[23]](#_bookmark25). This large fish (length 87.8 cm, weight 24500 g) likely accumulated high Cd concentrations throughout its long life. This agrees with the suggestions of Eisler [[30]](#_bookmark32) that Cd in liver is positively linked to the age of the

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| Table 6 e Maximum Permissible Limit (MPL) of heavy  metals in fish muscles (mg/g wet wt.) according to international standards. | | | | | | |
|  | Cu | Zn | Metals  Pb Cd | Fe | Mn | Reference |
| FAO (1983) | 30 | 30 | 0.5 0.05 |  |  | FAO [[46]](#_bookmark44) |
| FAO/WHO limit | 30 | 40 | 0.5 0.5 |  |  | FAO/WHO [[50]](#_bookmark48) |
| WHO 1989 | 30 | 100 | 2 1 | 100 | 1 | Mokhtar [[52]](#_bookmark49) |
| European |  |  | 0.2 0.05 |  |  | EC [[49]](#_bookmark47) |
| community |  |  |  |  |  |  |
| England | 20 | 50 | 2 0.2 |  |  | MAFF [[48]](#_bookmark46) |

fish. In this context, Ploetz et al. [[42]](#_bookmark40) stated that Cd concen- trations in the liver of king mackerel, *Scomberomorus cavalla* increased with increasing fork length. Furthermore, Kojadi- novic et al. [[43]](#_bookmark41) 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 con- centrations from zoobenthic predators [[44]](#_bookmark42). However, re- sults from several studies did not support this suggestion or even contradict it; Zhao et al. [[4]](#_bookmark11) found that *Cynoglossus gracilis* had the lowest level of metal accumulation among investigated species despite that it is a typical benthic fish. Also, Bustamante et al. [[45]](#_bookmark43) 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 gills of the benthic fish *Synodus* sp. when compared to other species. This finding may be attributed to higher levels of Fe in subsurface water of the Red Sea as recorded in the study of Sheridah et al. [[36]](#_bookmark35).

Although fish are mostly migratory and seldom settle in one place, metal accumulation in fish organs provides evi- dences of exposure to contaminated aquatic environment [[26]](#_bookmark28) 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 Suez. Also, the results from single species showed that, pelagic fish collected from Suez (*Epi- nephelus* sp., *Sardinella* sp., *Lethrinus* sp. and *T*. *mediterraneus*) recorded significantly the highest concentration of Cd in muscles, and relatively high Cd concentrations in other or- gans (liver and gills). These results agree with the previous studies that reported high metal levels in the seawater of Suez Bay when compared to those from the Red Sea proper [[11,14]](#_bookmark16), 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 [[9]](#_bookmark15). But in polluted aquatic habitats the concentration of metals in fish muscles may exceed the permissible limits for human consumption and imply severe health threats.

To asses public health risk of the Red Sea fish consump- tion, we compared metal levels in muscles of the current study ([Tables 2](#_bookmark4)e[4](#_bookmark4)) with the maximum permissible limits for human consumption (MPL) established by many different organizations ([Table 6](#_bookmark6)); as well as comparing metal concen- trations in muscles to those reported in similar fish species from the previous studies ([Table 7](#_bookmark7)). For the comparison to the data published as dry weight, they were converted to wet weight using converting factor 0.3; since the moisture is usually about 70% in the muscles [[22]](#_bookmark24).

With few exceptions, the metal concentrations in the examined fish species from the Red Sea fall below the (MPL)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Table 7 e Heavy metals in muscles (mg/g) of fish from the Red Sea and other regions. | | | | | | | | |
| Species | Site | Cu | Zn | Pb | Cd | Fe | Mn | Reference |
| *Epinephelus* sp.a | Red Sea | 0.66 | 3.37 | 0.53 | 0.17 |  |  | Emara et al., [[17]](#_bookmark20) |
| *Epinephelus fasciatus*b | Gulf of Aqaba | 0.97 | 9.13 | 4.80 | 0.97 | 5.93 | 1.63 | Abu Hilal and Ismail, [[37]](#_bookmark36) |
| *Lethrinus* sp.a | Red Sea | 0.40 |  | 0.89 | 0.45 |  |  | Abdelmoneim and El-Deek, [[18]](#_bookmark21) |
| *Siganus rivulatus*a | Alexandria | 1.59 | 7.95 | 0.73 | 0.25 | 37.53 | 0.54 | Khaled [[23]](#_bookmark25) |
| *Siganus rivulatus*b | Alexandria | 2.70 | 43.90 | 1.20 | 2.80 |  |  | Abdallah, [[22]](#_bookmark24) |
| *Sardinella aurita*b | Alexandria | 4.00 | 42.00 | 4.70 | 1.20 |  |  | Abdallah, [[22]](#_bookmark24) |
| *Trachurus mediterraneus*b | Black Sea (Turky) | 0.40 | 7.76 | <0.001 |  | 8.52 | 0.58 | Gorur et al., [[27]](#_bookmark29) |
| *Synodus saurus*b | Alexandria | 4.00 | 16.70 | 1.40 | 1.90 |  |  | Abdallah, [[22]](#_bookmark24) |
| *Thunnus albacares*a | Oman market |  |  | 0.03 | 0.01 |  |  | Al-Busaidi et al., [[6]](#_bookmark13) |
| *Epinephelus chlorostigma*a | Oman market |  |  | 0.05 | 0.02 |  |  | Al-Busaidi et al., [[6]](#_bookmark13) |
| *Scarus gibbus*a | Hurghada | 0.81 |  | 0.88 |  | 35.1 | 0.29 | Ahmed et al., [[20]](#_bookmark22) |
| *Nemipterus japonicus*a | Hurghada | 1.03 |  | 1.07 |  | 33.1 | 0.12 | Ahmed et al., [[20]](#_bookmark22) |
| *Nemipterus japonicus*a | Hurghada | 0.28 | 2.13 | 0.33 | 0.02 | 6.31 |  | El-Moselhy, [[15]](#_bookmark19) |
| *Lethrinus nebulous*b | Jeddah coast | 0.13 | 3.98 | 1.03 | 0.13 |  |  | Ali et al., [[51]](#_bookmark50) |
| *Lethrinus mahsena*b | Jeddah coast | 0.47 | 9.3 | 6.1 | 1.06 |  |  | Ali et al., [[51]](#_bookmark50) |
| *Caranx sexfaciatus*b | Jeddah coast | 0.91 | 5.33 | 3.4 | 0.9 |  |  | Ali et al., [[51]](#_bookmark50) |
| *Sardinella lemuru*a | Taiwan coastal water | 0.41 | 7.28 |  | <0.0005 | 7.72 | 0.73 | Chen and Chen [[41]](#_bookmark39) |
| 21 speciesb | Red Sea | 1.7e39.6 | 8.4e195 | 0.05e1.3 | 0.16e3.5 |  |  | Hanna, [[13]](#_bookmark18) |
| a Wet wt.  b Dry wt. | | | | | | | | |

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for human consumption recommended by FAO [[46]](#_bookmark44), WHO [[47]](#_bookmark45),

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MAFF [[48]](#_bookmark46) and EC [[49]](#_bookmark47), and were generally in the same range or

below the concentrations in the muscles of the same fish

species from pervious studies conducted in relatively unpol- luted waters.

The essential metals Cu, Zn, Fe and Mn were clearly below all the permissible limits for human consumption. While, the non-essential metal Pb was below the PML recommended by WHO [[47]](#_bookmark45) and MAFF [[48]](#_bookmark46), and was around or a little bit higher than the levels recommended by FAO [[46]](#_bookmark44) and FAO/WHO [[50]](#_bookmark48). Similarly Cd was generally below the PML in most cases except for the pelagic species from Suez that were higher than the levels recommended by FAO [[46]](#_bookmark44) and EC [[49]](#_bookmark47), but still below FAO/WHO [[50]](#_bookmark48), WHO [[47]](#_bookmark45) and MAFF [[48]](#_bookmark46) recommended limit.

The results in previous literatures were somewhat closer to or higher than our obtained data for similar fish species. For example, Abdallah [[22]](#_bookmark24) recorded the concentrations of Cd, Pb, Cu and Zn in muscles of *Sardinella aurita*, *S*. *rivulatus* and *Synodus saurus* from two main harbors in Alexandria, Egypt, who reported metal levels much higher than 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 recorded by Hanna [[13]](#_bookmark18), Abdelmoneim and El-Deek [[18]](#_bookmark21), Emara et al. [[17]](#_bookmark20), Ahmed et al. [[20]](#_bookmark22), El-Moselhy [[15]](#_bookmark19) and Ali et al. [[51]](#_bookmark50).

After all, fish in the Red Sea were found to be safe for consumption and do not pose a significant threat to the health of human consumers.

# Conclusions

Metal concentrations in the three studied locations were within the same range or below the concentrations in similar species from previous studies in the Egyptian waters or else- where. 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 ac- cumulations between fish even from the same 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. However, the levels of metals in pelagic fish and *Sardinella* sp. should be continuously monitored in potential polluted areas since pelagic fish showed a tendency to accumulate cadmium in muscles from polluted water, and *Sardinella* sp. accumulated high concen- trations of Cu, Zn, Cd, Fe and Mn in the muscles when compared to other species.

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1. [Medeiros RJ, dos Santos LM, Freire AS, Santelli RE,](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref1)

[Braga AMCB, Krauss TM, et al. Determination of inorganic](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref1) [trace elements in edible marine fish from Rio de Janeiro](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref1) [State, Brazil. Food Control 2012;23:535](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref1)e[41](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref1).

1. [Kris-Etherton P, Harris W, Appel L. Fish consumption, fish](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref2) [oil, omega-3 fatty acids, and cardiovascular disease.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref2) [Circulation 2002;106:2747](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref2)e[57](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref2).
2. [Yilmaz F, Ozdemir N, Demirak A, Tuna AL. Heavy metal](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref3) [levels in two fish species *Leuciscus cephalus* and *Lepomis*](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref3)[*gibbosus*. Food Chem 2007;100:830](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref3)e[5](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref3).
3. [Zhao S, Feng C, Quan W, Chen X, Niu J, Shen Z. Role of living](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref4) [environments in the accumulation characteristics of heavy](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref4) [metals in fishes and crabs in the Yangtze River Estuary,](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref4) [China. Mar Pollut Bull 2012;64:1163](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref4)e[71](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref4).
4. [Castro-Gonzalez MI, Mendez-Armenta M. Heavy metals:](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref5) [implications associated to fish consumption. Environ Toxicol](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref5) [Pharmacol 2008;26:263](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref5)e[71](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref5).
5. [Al-Busaidi M, Yesudhason P, Al-Mughairi S, Al-Rahbi WAK,](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref6) [Al-Harthy KS, Al-Mazrooei NA, et al. Toxic metals in](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref6) [commercial marine fish in Oman with reference to national](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref6) [and international standards. Chemosphere 2011;85(1):67](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref6)e[73](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref6).
6. [Rahman MS, Molla AH, Saha N, Rahman A. Study on heavy](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref7) [metals levels and its risk assessment in some edible fishes](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref7) [from Bangshi River, Savar, Dhaka, Bangladesh. Food Chem](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref7) [2012;134(4):1847](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref7)e[54](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref7).
7. [Meche A, Martins MC, Lofrano BESN, Hardaway CJ,](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref8) [Merchant M, Verdade L. Determination of heavy metals by](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref8) [inductively coupled plasma-optical emission spectrometry](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref8) [in fish from the Piracicaba River in Southern Brazil.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref8) [Microchem J 2010;94:171](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref8)e[4](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref8).
8. Elnabris KJ, Muzyed SK, El-Ashgar NM. 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 2013;13:44e51. [http://www.sciencedirect.com/science/](http://www.sciencedirect.com/science/article/pii/S1815385212000302-item1#item1) [article/pii/S1815385212000302-item1#item1](http://www.sciencedirect.com/science/article/pii/S1815385212000302-item1#item1).
9. [Mustafa C, Guluzar A. The relationships between heavy](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref10) [metal (Cd, Cr, Cu, Fe, Pb, Zn) levels and the size of six](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref10) [Mediterranean fish species. Environ Pollut 2003;121:129](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref10)e[36](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref10).
10. [Hamed MA, El-Moselhy Kh M. Levels of some metals in](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref11) [coastal water and sediments of the Red Sea, Egypt. J AMSE](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref11) [2000;61(1,2):43](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref11)e[58](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref11).
11. [Hanna RG, Muir GL. Red Sea corals as biomonitors of trace](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref12) [metal pollution. Environ Mon Assess 1990;14:211](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref12)e[22](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref12).
12. [Hanna RGM. Levels of heavy metals in some Red Sea fish](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref13) [before Hot Brine pools' mining. Mar Pollut Bull 1989;20:631](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref13)e[5](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref13).
13. [El-Moselhy Kh MI. Studies on the heavy metal level in some](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref14)

[economic fishes in the Suez Gulf. M. Sc. Thesis. Egypt: Fac.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref14) [Sci, Mansoura Univ.; 1993](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref14).

1. [El-Moselhy Kh MI. Response of fish to metal pollution along](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref15) [the Egyptian coast. Ph.D. Thesis. Egypt: Faculty of Science,](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref15) [TantaUniv.; 1996](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref15).
2. [EL-Moselhy Kh M. Accumulation of copper; zinc; cadmium](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref16) [and lead in some fish from the Gulf of Suez. Egypt. J Aquat](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref16) [Biol Fish 2000;3(1):73](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref16)e[83. 235](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref16)e[249](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref16).
3. [Emara HI, El-Deek MS, Ahmed NS. A comparative study on](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref17) [the levels of trace metals in some Mediterranean and Red](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref17) [Sea fishes. Chem Ecol 1993;8:119](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref17)e[27](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref17).
4. [Abdelmoneim MA, El-Deek MS. Lethrinus family: a model of](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref18) [edible Red Sea fish with low heavy metals accumulation. In:](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref18) [Proceedings of the 2nd Alexandria Conference (Food Sci.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref18) [Tech.). Egypt: Fac. Agri., Alexandria Univ.; 1992. pp. 439](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref18)e[48.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref18) [March 2](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref18)e[4](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref18).
5. [Abdolmoneim MA, El-Moselly KH, Hassan SH. Trace metal](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref19) [content in three fish species from northern part of the Suez](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref19)

[e gypti an j o ur nal o f b a sic a n d a pp l i ed sci en c e s 1 ( 2014) 9 7](http://dx.doi.org/10.1016/j.ejbas.2014.06.001) e[10](http://dx.doi.org/10.1016/j.ejbas.2014.06.001) 5

105

[Gulf, Red Sea, Egypt. J King Abdelaziz Univ Mar Sci](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref19) [1996;7:15](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref19)e[24](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref19).

1. [Ahmed NS, El-Deek MS, Emara HI. Heavy metals in the](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref20) [muscle and bone of some fish species from the Red Sea. J](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref20) [KAU Mar Sci 1996;7:25](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref20)e[31. Special Issue: Symp. Red Sea Mar](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref20) [Environ](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref20).
2. [FAO/SIDA. Manual of methods in aqautic environment](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref21) [research [Part 9. Analyses of metals and organochorines in](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref21) [fish]. FAO Fish Tech Pap. 212; 1983. p. 33](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref21).
3. [Abdallah MAM. Trace element levels in some commercially](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref22) [valuable fish species from coastal waters of Mediterranean](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref22) [Sea, Egypt. J Mar Syst 2008;73:114](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref22)e[22](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref22).
4. [Khaled A. Seasonal determination of some heavy metals in](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref23) [muscle tissues of *Siganus rivulatus* and *Sargus sargus* fish](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref23) [from El-Mex Bay and Eastern Harbor, Alexandria, Egypt.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref23) [Egypt J Aquat Biol Fish 2004;8(1):65](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref23)e[81](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref23).
5. [Moore JW, Ramamoorthy S. Heavy metals in natural waters:](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref24) [applied monitoring and impact assessment. New York:](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref24) [Springer-Verlag; 1984](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref24).
6. [Dhaneesh KV, Gopi M, Ganeshamurthy R, Kumar TTA,](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref25) [Balasubramanian T. Bio-accumulation of metals on reef](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref25) [associated organisms of Lakshadweep Archipelago. Food](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref25) [Chem 2012;131:985](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref25)e[91](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref25).
7. [Qadir A, Malik RN. Heavy metals in eight edible fish species](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref26) [from two polluted tributaries (Aik and Palkhu) of the River](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref26) [Chenab, Pakistan. Biol Trace Elem Res 2011;143:1524](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref26)e[40](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref26).
8. [Gorur FK, Keser R, Akcay N, Dizman S. Radioactivity and](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref27) [heavy metal concentrations of some commercial fish species](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref27) [consumed in the Black Sea Region of Turkey. Chemosphere](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref27) [2012;87:356](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref27)e[61](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref27).
9. [Roesijadi G. Metallothionein and its role in toxic metal](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref28) [regulation. Comp Biochem Physiol C 1996;113(2):117](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref28)e[23](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref28).
10. [Amiard JC, Amiard-Triquet C, Barka S, Pellerin J, Rainbow PS.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref29) [Metallothioneins in aquatic invertebrates: their role in metal](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref29) [detoxification and their use as biomarkers. Aquat Toxicol](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref29) [2006;76:160](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref29)e[202](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref29).
11. [Eisler R. Compendium of trace metals and marine biota2.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref30) [Amsterdam: Vertebrates Elsevier; 2010](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref30).
12. [Amundsen PA, Staldvik FJ, Lukin AA, Kashulin NA,](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref31)

[Popova OA, Reshetnikov YS. Heavy metal contamination in](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref31) [freshwater fish from the border region between Norway and](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref31) [Russia. Sci Total Environ 1997;201:211](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref31)e[24](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref31).

1. [Jose U, Carmen I, Jose M, Ignacio G. Heavy metals in fish](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref32) [(*Solea vulgaris*, *Anguilla anguilla* and *Liza aurata*) from salt](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref32) [marshes on the southern Atlantic coast of Spain. Environ Int](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref32) [2004;29:949](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref32)e[56](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref32).
2. [Dural M, Goksu MZL, Ozak AA. Investigation of heavy metal](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref33) [levels in economically important fish species captured from](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref33) [the Tuzla lagoon. Food Chem 2007;102:415](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref33)e[21](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref33).
3. [Kargin F. Metal concentrations in tissues of the freshwater](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref34) [fish *Capoeta barroisi* from the Seyhan River (Turkey). Bull](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref34) [Environ Contam Toxicol 1998;60:822](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref34)e[8](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref34).
4. [Avenant-Oldewage A, Marx HM. Bioaccumulation of](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref35) [chromium, copper and iron in the organs and tissues of](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref35) [*Clarias gariepinus* in the Olifants River, Kruger National Park.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref35) [Water Sanit 2000;26:569](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref35)e[82](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref35).
5. [Shriadah MA, Okbah MA, El-Deek MS. Trace metals in the](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref36) [water columns of the Red Sea and the Gulf of Aqaba, Egypt.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref36) [Water Air Soil Pollut 2004;153:115](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref36)e[24](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref36).
6. [Abu Hilal AH, Ismail NS. Heavy metals in eleven common](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref37) [species of fish from the Gulf of Aqaba, Red Sea. Jordan J Biol](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref37) [Sci 2008;1(1):13](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref37)e[8](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref37).
7. [EPA. Water quality criteria. Washington, DC: Environmental](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref38) [Protection Agency; 1972](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref38).
8. [Petkevich TA. Elemental composition of bony tissues of](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref39) [plankton-feeding and benthos-feeding fish from the](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref39) [Northwest part of the Black Sea. Dop Akad Nauk Ukr RSR Ser](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref39) [B 1967;29(2):142](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref39)e[6](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref39).
9. [Alturiqi AS, Albedair LA. Evaluation of some heavy metals in](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref40) [certain fish, meat and meat products in Saudi Arabian](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref40) [markets. Egypt J Aquat Res 2012;38(1):45](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref40)e[9](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref40).
10. [Chen Y, Chen M. Heavy metal concentrations in nine species](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref41) [of fishes caught in coastal waters off Ann-Ping, S. W. Taiwan.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref41) [J Food Drug Anal 2001;9(2):107](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref41)e[14](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref41).
11. [Ploetz DM, Fitts BE, Rice TM. Differential accumulation of](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref42) [heavy metals in muscle and liver of a marine fish (King](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref42) [Mackerel, *Scomberomorus cavalla* Cuvier) from the northern](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref42) [Gulf of Mexico, USA. Bull Environ Contam Toxicol](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref42) [2007;78:134](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref42)e[7](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref42).
12. [Kojadinovic J, Potier M, Le Corre M, Cosson RP,](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref43)

[Bustamante P. Bioaccumulation of trace elements in pelagic](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref43) [fish from the western Indian Ocean. Environ Pollut](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref43) [2007;146:548](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref43)e[66](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref43).

1. [Yi YJ, Yang ZF, Zhang SH. Ecological risk assessment of](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref44) [heavy metals in sediment and human health risk](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref44) [assessment of heavy metals in fishes in the middle and](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref44) [lower reaches of the Yangtze River basin. Environ Pollut](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref44) [2011;159:2575](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref44)e[85](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref44).
2. [Bustamante P, Bocher P, Che](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref45)e´[rel Y, Miramand P, Caurant F.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref45) [Distribution of trace elements in the tissues of benthic and](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref45) [pelagic fish from the Kerguelen Islands. Sci Total Environ](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref45) [2003;313:25](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref45)e[39](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref45).
3. [FAO. Compilation of legal limits for hazardous substances in](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref46) [fish and fishery products. FAO Fishery Circular No. 464. Food](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref46) [and Agriculture Organization; 1983. pp. 5](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref46)e[100](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref46).
4. [WHO (World Health Organization). Heavy metals](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref47)

[-environmental aspects; 1989. Environment health criteria.](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref47) [No. 85. Geneva, Switzerland](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref47).

1. [MAFF (Ministry of Agriculture, Fisheries and Food).](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref48) [Monitoring and surveillance of non-radioactive](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref48) [contaminants in the aquatic environment and activities](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref48) [regulating the disposal of wastes at sea, 1997. In: Aquatic](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref48) [environment monitoring report No. 52. Lowestoft, UK:](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref48) [Center for Environment, Fisheries and Aquaculture Science;](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref48) [2000](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref48).
2. [EC (European Community). Commission regulation No 78/](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref49) [2005 (pp. L16/43](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref49)e[L16/45). Official J Eur Union 2005 [20.1.2005]](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref49).
3. [FAO/WHO. Evaluation of certain food additives and the](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref50) [contaminants mercury, lead and cadmium; 1989. WHO](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref50) [Technical Report Series No. 505](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref50).
4. [Ali AA, Elazein EM, Alian MA. Investigation of heavy metals](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref51) [pollution in water, sediment and fish at Red Sea- Jeddah](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref51) [Coast- KSA at two different locations. J Appl Environ Biol Sci](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref51) [2011;1(12):630](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref51)e[7](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref51).
5. [Mokhtar M. Assessment level of heavy metals in *Penaeus*](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref52)[*monodon* and *Oreochromis* spp. in selected aquaculture ponds](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref52) [of high densities development area. Eur J Sci Res](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref52) [2009;30(3):348](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref52)e[60](http://refhub.elsevier.com/S2314-808X(14)00025-6/sref52).