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Trace Elements Pollution in Water, Sediments, and Marine Fish Muscles from Suez Gulf, Red Sea, Egypt: Environmental and Health Consequences

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ABSTRACT

This study aimed to check the levels of 12 elements (As, B, Ni, Cu, Zn, Fe, Mn, Pb, Ba, Cd, Cr, and Al) in water, sediments, and 3 species of marine fish from the Suez Gulf during the summer of 2024, focussing on the environmental and health problems linked to each element. The findings showed that the amounts of trace elements in the water and sediment samples varied. Boron (B) had the maximum levels in water (3.57 ± 0.09µg/ mL), while zinc (Zn) recorded the minimum (0.011 ± 0.002µg/ mL). The sediment revealed iron (Fe) to be the most abundant element (1539 ± 325µg/kg-dw), followed by aluminium (Al) and manganese (Mn). However, muscles showed that sigan fish (*Siganus rivulatus*, Forsskål & Niebuhr, 1775) had the maximum level of Al (81.40±3.88 µg/g-ww) and the minimum for cadmium (Cd) (0.41 ± 0.01 µg/g-ww). Arsenic (As) levels exceeded the allowed limits in all examined species, while Zn and copper (Cu) levels remained within safe limits according to international standards. The pollution index and contamination degree revealed moderate to high contamination of arsenic in fish species, especially in bongus fish (*Lethrinus borbonicus*, Forsskål, 1775) and harid fish (*Chlorurus sordidus* Forsskål, 1775). There is no immediate health risk associated with consuming these species, according to the estimated daily intake and hazard quotient values, non-essential elements like arsenic may pose health hazards, particularly for children. In order to mitigate element pollution in marine environments, the study emphasizes the necessity of additional environmental monitoring and management.

INTRODUCTION

The largest significant commercially fished fishery in the Red Sea is the Suez Gulf. Since it connects the Red Sea and the Mediterranean Sea, it is the best place to spawn **(Saber *et al.*, 2022)**. Comparing fish to other animal flesh, it forms a significant part of the human diet. It is a vital source of protein, vitamins, minerals, and omega-3 unsaturated fatty acids, additionally it is also easily digested by the human digestive system **(Mohanty *et al.*, 2015; Miao *et al.*, 2020)**. More people are becoming aware of the health benefits of eating fish in recent years. However, fish ingestions at least twice a week is recommended since it is known to reduce the risk of a number of diseases, including triglyceride levels, asthma, arrhythmia, heart attacks, thrombosis, stroke, and preterm birth **(Zhong *et al.*, 2018; Tanamal *et al.*, 2021)**.

Fish have a significant role in delivering toxins to consumers **(Verbeke *et al.*, 2005)** and are at the top of marine environments and at the highest trophic stage in the food chain **(Kwaansa-Ansah *et al.*, 2019)**. Aquatic organisms ingest small amounts of trace elements through their water intake, whereas consumers consume larger amounts through the food chain, potentially having both short-term and long-term health impacts **(Afifi *et al.*, 2024)**. Trace elements are consumed by people through their dietary habits and are passed up the food chain **(Schenone *et al.*, 2014)**. Aquatic organisms face significant threats from the contamination of their habitats by both inorganic and organic pollutants, as documented by **Shahjahan *et al.* (2022)**.

Two categories of inorganic pollutants in the environment: the first, essential elements (iron, copper, selenium, and zinc), while the second, non-essential elements (cadmium, arsenic, mercury, cobalt, and lead) based on physiological requirements **(McEneff *et al.*, 2017)**. According to **Yipel *et al.* (2021)**, trace element residues can enter aquatic habitats through a number of routes, such as the release of untreated or insufficiently treated household, industrial, and agricultural waste. Consumers, including people, can be exposed to trace elements through the consumption of contaminated organisms, which can lead to acute and long-term health implications **(Abbas *et al.*, 2022a)**. The levels of trace elements in fishes are subject to various influencing factors. It is crucial to identify fish species with elevated metal levels to ensure consumer awareness and safety. The extent of contamination can vary based on factors such as contamination sources, fish tissues, fish species, trophic levels, collection sites, and feeding habits **(Weber *et al.*, 2013)**.

Pervious studies investigatED the trace element levels in the muscular tissue of fish in both freshwater and marine water environments for a number of decades in various countries around the world, such as Tunisia **(Ayed *et al.*, 2011)**, Bosnia and Herzegovina **(Djedjibegovic *et al.*, 2012)**, China **(Zhao *et al*., 2012)**, Italy **(Copat *et al.*, 2013)**, Malaysia **(Jamil *et al.*, 2014)**, Egypt **(Ghanem, 2014; Abdel-Wahab *et al.*, 2017; Khader *et al.*, 2022; Abbas *et al.*, 2022 a&b**; **Afifi *et al.*, 2024; El-Shorbagy *et al.*, 2024**; **Abbas 2024)**, India **(Kumar *et al.*, 2018)**, Türkiye **(Töre *et al.*, 2021)**, Bangladesh **(Alam *et al.*, 2023; Pinkey *et al.*, 2024)**, Pakistan **(Haseeb-ur-Rehman *et al.*, 2023)**, and Nigeria **(Adebiyi *et al.*, 2024**. Monitoring trace elements in fish muscle tissue has become crucial due to the health hazards associated with the accumulation of trace elements through fish eating. In order to determine the possible health concerns associated with consuming marine fish, it is crucial to measure the levels of trace elements in their muscle.

Possible health hazards connected to consuming trace elements of concern have been recognized for several decades. It is known that accumulations of trace elements can endanger human health in both non-carcinogenic and carcinogenic ways **(Irshad *et al.*, 2024)**. It poses significant health risks to humans, including renal failure, bone deformities, and liver dysfunction. These risks arise from their persistent and nondegradable nature within the body's internal organs **(Kim *et al.*, 2015)**. The current investigation aimed to (1) monitor the concentrations of 12 trace elements in sediment, water, and three fish spp.; (2) identify factors influencing metal bioaccumulation in fish; (3) evaluate the environmental impact of these elements on aquatic environments; and (4) assess health risks, including non-cancer and cancer risks, from consuming these fish.

MATERIALS AND METHODS

Samples collection

Water samples were collected using a Ruttner sampler from three different areas in the Gulf of Suez, with three replicates per area. Simultaneously, sediment samples were gathered during the summer of 2024 (Fig. 1). Additionally, three fish species (five specimens per species) were obtained from fishermen in Suez City.

The first species, bongus fish (*Lethrinus borbonicus*), is a carnivorous member of the Lethrinidae family. It had an average total weight of 199.31 ± 11.04 g, a standard length of 19.11 ± 1.12 cm, and a total length of 22.64 ± 1.03 cm. The second species, harid fish (*Chlorurus sordidus*), also carnivorous but belonging to the Scaridae family, had an average total weight of 362.33 ± 22.27 g, a standard length of 25.65 ± 2.04 cm, and a total length of 32.11 ± 3.54 cm. The third species, sigan fish (*Siganus rivulatus*), is a herbivorous fish from the Siganidae family, with an average total weight of 167.40 ± 6.05 g, a standard length of 18.09 ± 1.02 cm, and a total length of 21.69 ± 1.11 cm.

All fish specimens were immediately transported to the laboratory in ice-filled containers. A minimum of 10 grams of edible dorsal muscle tissue was extracted from each specimen. The muscle samples were then frozen and stored in plastic bags for later analysis.

Fig. 1. A map displaying the locations of the water and sediment samples collection stations in Egypt's Suez Gulf

Trace element measurements

The boron (B), copper (Cu), lead (Pb), zinc (Zn), chromium (Cr), barium (Ba), aluminium (Al), nickel (Ni), arsenic (As), manganese (Mn), iron (Fe), and cadmium (Cd) levels were measured in sediment, water, and three fish samples (n=5). In accordance with APHA recommendations, 500 mL of water samples were acidified with HCl (37%) and HNO_3 (65%) after being filtered through a 0.45µm filter **(APHA, 2023)**. Samples of sediment were mixed, dried at 105°C, and then sieved using a 63µm screen. Then, in accordance with EPA protocol **(USEPA, 2023)**, 1.0g of the sieved sediment was digested in a covered Teflon vessel (Anton-Paar microwave digestion machine) using HNO_3 (9 mL) and HCl (3mL). 5mL of HNO_3 (65%) and 1mL of H_2O_2 (30%) were added to digestion tubes with about 0.5g of each fresh muscle sample. On a hot plate, the mixture had been heated until it was completely digested. The digested specimens were then transferred to volumetric bottles and diluted with 1 percent HNO_3 until they reached a final volume of 25mL **(AOAC, 2012)**. Inductively coupled plasma optical emission spectrometry (ICP-OES, USA) was used to measure the amounts of trace elements in diluted sediment, water, and fish samples. A quality control sample, an external reference, and standard reference materials are used to guarantee the precision and accuracy of the findings. The recovery rates for standard reference metals ranged between 90% and 110%. The amount of water was expressed in µg/L, while the amounts of fish muscle and sediment were expressed in µg/g on a wet weight basis (ww-b) and dry weight basis (dw-b), respectively. Details of the quantification ranges (LOQ) and detection ranges (LOD) for the studied elements are given in Table (1S).

Ecological risk assessments

The contamination degree (CD) and the metal pollution index (MPI) are two of the measures used to assess the level of metal pollution in aquatic species **(Tahity *et al.*, 2022)**.

CD measurements

The CD was calculated using the trace element levels found in marine fish from the Suez Gulf. The CD was determined by the equation:

$$\mathbf{CD = C\text{-}fish \,/\, C\text{-}background}$$

Where, C-fish represents the level of trace elements in fish (µg/g-ww) and C-background denotes the background levels of Pb, Cu, Zn, Cd, Fe, and Ni cited in Abbas (2023). The CD values offer a clear indication of contamination levels. A CD value of 1 or less indicates minimal contamination, reflecting negligible pollution. Values between 1 and 2 signify low contamination, suggesting a minor presence of pollutants. A CD range of 2 to 3 represents moderate contamination, indicating a noticeable environmental impact. CD values exceeding 3 are categorized as high contamination, reflecting significant environmental pollution.

MPI measurements

The MPI provides an integrated assessment of trace element contamination. The MPI was computed using the formula:

$$\mathbf{MPI = (C_1 \times C_2 \times C_3 \times \cdots\cdots \times C_x)^{1/n}}$$

Where, C_1, C_2, C_3, ..., Cx displayed the element levels in studied muscles (µg/g-ww), and n is the number of measured elements **(Tahity *et al.*, 2022)**. MPI values are classified into four pollution levels: a value of 1 or less is deemed safe, indicating minimal pollution. Values between 2 and 3 denote slight pollution, reflecting a minor presence of contaminants. An MPI extending from 3 to 5 indicates moderate pollution, suggesting a more substantial environmental impact. Values greater than 10 are classified as heavily polluted, signifying severe contamination and significant environmental concern.

Health risk assessment

The estimated daily intake (EDI) and non-carcinogenic and carcinogenic risk indices based on the amounts of the studied element in the muscle tissues were used to assess the possible health risks associated with eating fish muscle tissue **(USEPA, 2018)**.

EDI measurements

The EDI was calculated to evaluate exposure levels since it represents the average daily intake of a specific trace element throughout the lifespan as a result of eating fish muscle tissue **(Mwakalapa *et al.*, 2019)**:

$$\mathbf{EDI = ((EP \times IR \times C \times ER) / (BW \times AT)) \times 10^{-3}}$$

Where, the EP represents the lifespan of the exposure period (70 years), and the IR represents the rate of fish consumption by adults (41 g/day) and children (27 g/day) **(USEPA, 2018)**; BW is the body weight of the adult and child (70 kg and 30 kg, respectively); AT is the mean lifetime (365 days x 70 years); C is the element content in the studied muscles (µg/g ww-b); and ER (365 days year-1) is the exposure rate **(USEPA, 2018)**.

Target hazard quotient (THQ) measurements

The THQ was used to determine non-carcinogenic health issues associated with the ingestion of heavy metal pollution found in the studied muscles It was calculated by comparing the EDI of a trace element to its oral reference dose.

$$\mathbf{THQ = EDI / RfD}$$

Where, RfD is for the oral reference dose (µg/g/day), and the RfD values for the exmined elements are as follows: arsenic 0.003, copper 0.04, nickel 0.02, barium 0.2, lead 0.00357, iron 0.7, manganese 0.14, and zinc 0.3 **(USEPA, 2018)**.

Hazard index (HI) measurements

The HI is an additional computational formula that adds up the THQ values for the studied elements in order to show the influence of non-carcinogenic risks **(Cui *et al.*, 2015)**:

$$\mathbf{HI = THQ\ (Mn) + THQ\ (B) + THQ\ (As) + THQ\ (Zn) + THQ\ (Fe) + THQ\ (Ni) + THQ\ (Cr) + THQ\ (Al) + THQ\ (Cu) + THQ\ (Ba) + THQ\ (Cd) + THQ\ (Pb)}$$

Carcinogenic risk (CR) measurements

The CR values were calculated to ascertain the increasing risk of cancer associated with ingesting of studied elements in fish spp:

$$\mathbf{CR = EDI \times CSF}$$

Where, CSF stands for the carcinogenic slope factor; 1.5µg/g/day for As, 0.0038µg/g/day for Cd, 0.0085µg/g/day for Pb **(USEPA, 2016)**.

Statistical measurements

Excel was utilized to do statistical analysis using SPSS (version 22). Levene's test was used to evaluate the results' normal distribution and confirm homogeneity of variance. One-way analysis of variance (ANOVA) was employed to identify statistically significant differences ($P < 0.05$) in the concentrations of the studied elements in water, sediments, and fish spp. **(Dytham, 2011)**. Finally, the data were displayed as means ± standard deviation in tables.

RESULTS AND DISCUSSION

Trace elements levels in water samples

Element levels in the Gulf of Suez water fluctuated, as shown in Table (1), with the highest recorded level for B being 35.7±0.96µg/ L and the lowest for Cr being 2.1±0.2µg/ L. However, the extending of these metals was as follows: aluminium > boron > iron > barium > zinc > arsenic > copper > lead > chromium. In contrast, Cd, Mn, and Ni were not detectable in studied water samples. Comparing the element levels in water samples to the established recommendations, it showed that they were within acceptable ranges **(WHO 2011)**. The arsenic concentration in the studied water was found to be 4.5±0.27µg/ L, which is higher than the range reported by **Hou *et al.* (2024)** (0.82-0.86 µg/L). In contrast, the Pb concentration in the water from the Suez Gulf, Red Sea (3.3±0.10 µg/L), was notably within the values mentioned by **El-Metwally *et al.* (2019)** (1.24 - 4.51 µg/L), while **Hou *et al.* (2024)** documented even higher levels (1.76-2.57 µg/L). Similarly, **Mahmoud *et al.* (2023)** and **Magdy *et al.* (2024)** reported 0.44-0.75 and 0.0113 µg/L, respectively. The Cr concentration in the studied water was found to be 2.1±0.2 µg/L, which is within the values mentioned by **Hou *et al.* (2024)** (1.48-12.2 µg/L). The study also recorded an average Cu concentration in the water of the Suez Gulf, Red Sea **(**3.7±0.3 µg/L**)**. This value is lower than those reported by **El-Metwally *et al.* (2019)**, **Mahmoud *et al.* (2023)**, and **Hou *et al.* (2024)** (0.85-2.61, 0.0124, and 3.36-3.60 µg/L, respectively). Fe concentration in the Suez Gulf water, Red Sea, was found to be 17.7±0.72 µg/L, which is notably within the values mentioned by **El-Metwally *et al.* (2019)** and **Magdy *et al.* (2024)** (8.44 - 33.71 µg/L and 19.10-26.96 µg/L). On the other hand, it was lower than those mentioned by **Mahmoud *et al.* (2023)** (0.147 µg/L). Zn concentration in the Suez Gulf water, Red Sea, was found to be 11.45±0.62 µg/L, which was notably within the values revealed by **El-Metwally *et al.* (2019)** (2.13 - 14.42 µg/L), 8.96-17.26 µg/L **(Hou *et al.*, 2024)**, while it was higher than those mentioned by

Mahmoud *et al.* (2023) and **Magdy *et al.* (2024)** (0.012 and 2.54-6.30 µg/L, respectively)

Trace elements levels in sediment samples

Table (2) shows the concentrations of the trace elements in the sediment samples varied, with Cu exhibiting the lowest level at 1.17 ± 0.23 µg/g-dw and Fe displaying the highest level at 1539 ± 325 µg/g-dw. In descending order, the elements are ranked as follows: iron > aluminium > manganese > zinc > barium > boron > chromium > arsenic > nickel > lead > copper. Notably, Cd was below detection limits **(**ND**)** in the sediment.

The arsenic concentration in the studied sediment was found to be 2.57 ± 0.23 µg/g-dw, which is within the range mentioned by **Hou *et al.* (2024)** (1.68–3.12 µg/g-dw). In contrast, the lead (Pb) concentration in the current study (2.23 ± 0.83 µg/g-dw) from the Suez Gulf, Red Sea, was notably lower than those reported from other coastal regions. For example, **El-Sorogy *et al.* (2024)** mentioned a concentration of 41.98 µg/g-dw in the Hurghada coastal area of the Red Sea. However, **Kodat and Tepe (2023)** documented even higher levels (60.64 µg/g-dw) in the Black Sea. Similarly, **Kahal *et al.* (2020)** reported 33 µg/g-dw in the Red Sea, Saudi Arabia. These values are in contrast with historical baseline levels such as those from **Turekian and Wedepohl (1961)** for background shale (90 µg/g-dw) and **Taylor (1964)** for background continental crust (100 µg/g-dw), suggesting that natural geological levels typically surpass those observed in this study. Furthermore, the lead values found in this study are still significantly below critical contamination limits, as the **FAO/WHO (2001)** maximum allowed limit (100 µg/g-dw).

The chromium concentration in the studied sediment (6.27 ± 0.67 µg/g-dw) from the Suez Gulf, Red Sea, was significantly lower compared to values reported in other marine environments. For instance, in Jiaozhou Bay, China, **Hou *et al.* (2024)** found that the amounts of Cr ranged from 41.39 to 72.29 µg/g-dw. However, the copper concentration of 1.17 ± 0.23 µg/g-dw in the studied sediments. This value is similar to the concentration of 1.23 µg/g-dw found in Hurghada coastal sediments, as documented by **El-Sorogy *et al.* (2024)**. However, **Kahal *et al.* (2020)** and **Kodat and Tepe (2023)** have detected much higher Cu concentrations in different marine habitats (31.6 and 45.66 µg/g-dw, respectively). Similarly, **El-Sorogy *et al.* (2016)** and **Hou *et al.* (2024)** reported values ranging from 24.51 to 30.69 µg/g-dw in the Mediterranean Sea, Egypt, and Jiaozhou Bay, China, respectively. When compared with global geochemical background levels, Cu concentrations in shale sediments are reported to be 45 µg/g-dw **(Turekian & Wedepohl, 1961)**, while continental crust levels reach 55 µg/g-dw **(Taylor, 1964)**, indicating that the Cu levels found in the Suez Gulf sediments are lower. The MPL (100 µg/g-dw) for Cu in marine sediments, as set by **FAO/WHO (2001)**.

The iron concentration in the studied sediments, was recorded at an average of 1539 ± 325 µg/g-dw. This value is lower than those reported for Red Sea sediments, Saudi Arabia (2432 µg/g-dw, **Kahal *et al.*, 2020)** and the Hurghada coastal area **(**346 µg/g-dw, **El-Sorogy *et al.*, 2024)**. Comparisons with other marine environments reveal even higher concentrations, with **El-Sorogy *et al.* (2016)** documenting 109,560 µg/g-dw in the Mediterranean Sea, Egypt and **Kodat and Tepe (2023)** reporting 27,646 µg/g-dw in the Black Sea. When compared to geochemical background levels, Fe concentrations in shale sediments are estimated at 47,200 µg/g-dw **(Turekian & Wedepohl, 1961)**, and continental crust levels reach 56,300 µg/g-dw **(Taylor, 1964)**, indicating that Fe levels in the Suez Gulf sediments are significantly lower than natural background concentrations. The MPL for Fe in marine sediments, as set by **FAO/WHO (2001)**, is 5000 µg/g-dw, with the Fe concentrations recorded in the Suez Gulf being well below this threshold, suggesting no Fe-related pollution in the region.

The zinc concentration in the Suez Gulf sediments was found to be 15.47 ± 1.22 µg/g-dw, which is relatively low compared to other marine environments. For instance, **El-Sorogy *et al.* (2024)** reported 7.47 µg/g-dw in the Hurghada coastal area, Red Sea. On the other hand, **El-Sorogy *et al.* (2016)** mentioned a significantly higher concentration in the Mediterranean Sea, Egypt (183.23 µg/g-dw). Other studies from the Black Sea (94.16 µg/g-dw) and Jiaozhou Bay, China (76.07-96.19 µg/g-dw), also reported higher concentrations. By comparing these findings with the **FAO/WHO**-established MPL for zinc (300 µg/g-dw), it can be concluded that the levels of zinc pollution in these aquatic habitats fall within the allowed limits.

The manganese concentration in the current study was found to be 56.27 ± 5.78 µg/g-dw. A study by **El-Sorogy *et al.* (2024)** mentioned a lower value of 49.36 µg/g-dw in the Hurghada coastal area, Red Sea. **Kodat and Tepe (2023)** recorded a much higher concentration of 571.87 µg/g-dw in the Black Sea sediment. However, **El-Sorogy *et al.* (2016)** documented 553 µg/g-dw in the Mediterranean Sea sediment, Egypt. Other investigations have found manganese concentrations in background shale **(**850 µg/g-dw, **Turekian** and **Wedepohl, 1961)** and continental crust **(**950 µg/g-dw, **Taylor, 1964)**. The MPL for manganese set by **FAO/WHO (2001)** is 2000 µg/g-dw, and compared to this threshold, the manganese concentrations in the studied sites are significantly lower.

Finally, the nickel concentration in the current study was found to be 2.57 ± 0.54 µg/g-dw. **El-Sorogy *et al.* (2024)** recorded a lower value of 1.73 µg/g-dw in the Hurghada coastal sediment, Red Sea. **Kodat and Tepe (2023)** mentioned a higher value of 27.29 µg/g-dw in the Black Sea. Additionally, **Kahal *et al.* (2020)** documented 20 µg/g-dw in the Red Sea sediment, Saudi Arabia. **El-Sorogy *et al.* (2016)** reported a significantly higher concentration of 480.86 µg/g-dw in the Mediterranean Sea, Egypt. The nickel levels in the Suez Gulf sediments are lower than the background values in shale **(**68 µg/g-dw, **Turekian & Wedepohl, 1961)** and the continental crust **(**75 µg/g-dw, **Taylor, 1964)**. The MPL for nickel set by **FAO/WHO (2001)** is 50 µg/g-dw. Based on these results, it is evident that nickel concentrations in many of the studied sites exceed the MPL, indicating elevated pollution levels in certain aquatic environments.

Table 1. Comparison of trace element levels **(**µg/L; Cu, Pb, Zn, Cr, Al, Ni, As, Mn, Fe, and Cd**)** in the studied water samples **(**n=5**)** across different investigations

	Non-essential elements					**Essential elements**			
	As	**Al**	**Ba**	**Pb**	**Cr**	**Cu**	**Fe**	**B**	**Zn**
Current study	4.5±0.27	63.45±1.01	16.2±0.53	3.3±0.1	2.1±0.2	3.7±0.3	17.7±0.72	35.7±0.96	11.45±0.62
El-Metwally *et al.* (2019)				1.24 - 4.51		0.85 to 2.61	8.44 - 33.71		2.13 - 14.42
Mahmoud *et al.* (2023)				0.0113		0.0124	0.147		0.012
Hou *et al.* (2024)	0.82-0.86	--	--	1.76-2.57	1.48-12.2	3.36-3.60	--	--	8.96-17.26
Magdy *et al.* (2024)				0.44-0.75			19.10-26.96		2.54-6.30

Table 2. Comparison of the levels of the studied elements **(**µg/g-dw-b, n=5**)** in the sediment samples across different investigations

	Non-essential elements						Essential elements						Location
	As	**Al**	**Ba**	**Pb**	**Cr**	**Cd**	**Cu**	**Fe**	**B**	**Zn**	**Mn**	**Ni**	
Current study **(**µg/g-dw, n=5**)**	2.57±0.23	1021±123	8.60±0.43	2.23±0.83	6.27±0.67	ND	1.17±0.23	1539±325	8.47±0.67	15.47±1.22	56.27±5.78	2.57±0.54	
El-Sorogy *et al.* (2024)				41.98		0.14	1.23	346		7.47	49.36	1.73	Hurghada coastal, Red Sea,
Kodat and **Tepe (2023)**				60.64		0.20	45.66	27,646		94.16	571.87	27.29	Black Sea
Kahal *et al.* (2020)				33		0.51	31.6	2432		28.5	--	20	Jazan coastal area, Red Sea, Saudi Arabia
El-Sorogy *et al.* (2016)				0.18		28.88	24.57	109,560		183.23	553	480.86	Mediterranean Sea, Egypt
Hou *et al.* (2024)	1.68-3.12			26.83-33.57	41.39-72.29	0.074-0.092	24.51-30.69			76.07-96.19			Jiaozhou Bay, China
Turekian and **Wedepohl, (1961)**				90		0.30	45	47,200		95	850	68	Background shale
Taylor (1964)				100		0.20	55	56,300		70	950	75	Background continental crust
FAO/WHO (2001)				100		3	100	5000		300	2000	50	MPL

Trace elements levels in fish species

A comparison of trace element levels in the sigan fish, bongus fish, and harid fish across various studies is represented in Table (4). However, Table (3) represents the maximum allowable limit (MPL) for trace elements (µg/g wet weight) in the fish muscles in accordance with international regulations. The studied fish exhibit As levels ranging from 1.44 to 3.53 µg/g-ww. These outcomes were below the range described by **Mziray and Kimirei (2016)**, which varied between 3.43 and 18.52 µg/g-ww. Nonetheless, they concurred with the results of **Abbas *et al.* (2024)**, who recorded levels extending from 0.50 to 3.59 µg/g-ww. Compared to **Al-Amri *et al.* (2021)**, who observed significantly decreased levels extending from 0.002 to 0.02 µg/g-ww, the present outcomes indicate relatively higher levels. In addition, the present study's results fell within the broader range described by **El-Shorbagy *et al.* (2024)** (0.48–5.10 µg/g-ww). In contrast, As levels documented by **Hussein *et al.* (2023)** in three marine spp. (1.03–1.13 µg/g-ww) were slightly below those found in the current study.

The Al concentrations in the muscles of the studied species varied from 63.95 to 81.40 µg/g-ww. These levels were significantly higher than those described by **El-Shorbagy *et al.* (2024)**, who recorded a range of 1.93 to 4.36 µg/g-ww, and **Abbas *et al.* (2024)**, who observed concentrations between 0.80 and 4.21 µg/g-ww. Similarly, the present study's values exceeded those documented by **Hussein *et al.* (2023)**, which varied from 1.38 to 2.11 µg/g-ww for three marine spp. However, the Al levels in this study partially overlapped with the range described by **Mziray and Kimirei (2016)**, which varied from 19.44 to 87 µg/g-ww.

The Pb concentrations in the muscles of the studied species varied from 1.38 to 2.18 µg/g-ww. These outcomes were greater than those described by **El-Moselhy *et al.* (2014)**, who recorded amounts between 0.25 and 0.50 µg/g-ww, and **Zaghloul *et al.* (2022),** who documented levels between 0.26 and 1.04 µg/g-ww. Likewise, the current results were higher than those published by **Mziray and Kimirei (2016)**, **Younis *et al.* (2021)** and **Hussein *et al.* (2023)** (0.05–0.14, 0.15–0.17, and 0.06–0.17 µg/g-ww, respectively). Furthermore, the Pb in this investigation exhibits lower concentrations than those described by **El-Shorbagy *et al.* (2024)**, who recorded a range of 2.12 to 6.83 µg/g-ww, and slightly below the upper range observed by **Abbas *et al.* (2024)** (0.59–4.81 µg/g-ww). The results also aligned closely with those from **Al-Amri *et al.* (2021)** and **Yakamercan *et al.* (2021)** (0.00–2.75 and 0.72–4.2 µg/g-ww, respectively).

The Cr concentrations in the muscles of the studied species varied from 0.60 to 1.90 µg/g-ww. These outcomes were lower than those described by **Younis *et al.* (2021)**, **Abbas *et al.* (2024)** and **El-Shorbagy *et al.* (2024) (**7.63 to 23.6, 2.29-5.43, and 1.97-5.25 µg/g-ww, respectively). In contrast, the Cr levels in the present study were higher than those recorded by **Hilal and Ismail (2008)**, **Mziray and Kimirei (2016)**, and **Al-Amri *et al.* (2021)** (0.21–2.08, 0.10–0.29 and 0.01–0.02 µg/g-ww, respectively). However, the Cd concentrations in the muscles of the studied species varied from 1.44 to

3.53 µg/g-ww. These outcomes are notably higher compared to the findings of **El-Moselhy *et al.* (2014)**, **Zaghloul *et al.* (2022)** and **Hussein *et al.* (2023), (**0.04 to 0.38, 0.54 to 1.09 and 0.03 to 0.11 µg/g-ww, respectively).

The Cu concentrations in the muscles of the studied species fluctuated between 10.96 and 21.84 µg/g-ww. These levels were significantly higher than those described by **El-Moselhy *et al.* (2014)**, **Al-Amri *et al.* (2021), Yakamercan *et al.* (2021)**, and **Zaghloul *et al.* (2022) (**0.17-0.74, 0.09-1.31, 0.07-0.77, and 0.381-0.970 µg/g-ww, respectively**)**. Compared to **El-Shorbagy *et al.* (2024)**, who observed a Cu range of 2.11 to 10.29 µg/g-ww, the Cu concentrations in this current investigation were higher, yet aligned with those described by **Abbas *et al.* (2024)** (10.33 to 25.85 µg/g-ww). In addition, **Mziray** and **Kimirei (2016)** noted Cu levels of 1.65 to 4.71 µg/g-ww, which were also lower than the outcomes of the current investigations.

The Fe concentrations in the muscles of the studied species fluctuated between 31.26 and 63.96 µg/g-ww. These levels were comparable to those described by **El-Shorbagy *et al.* (2024)**, who observed Fe levels extending from 31.80 to 81.35 µg/g-ww. Similarly, **Abbas *et al.* (2024)** recorded Fe levels between 36.86 and 135.96 µg/g-ww, which overlap with the higher end of the present study's findings. In contrast, the Fe levels in the current investigations were significantly higher than those described by **El-Moselhy *et al.* (2014)** and **Al-Amri *et al.* (2021)** (1.15-10.9 and 6.84-20.81 µg/g-ww, respectively). **Zaghloul *et al.* (2022)** also noted lower Fe levels, extending from 13.6 to 29.1 µg/g-w. In contrast, the findings of **Mziray** and **Kimirei (2016)**, who recorded Fe levels of 34.02 to 103.29 µg/g-ww, were in agreement with the outcomes of the current investigations, especially at the upper end.

The Zn levels in the present study varied from 22.98 to 49.69 µg/g-ww across three marine spp. These levels were notably higher than those described by **El-Shorbagy *et al.* (2024)**, who observed that the Zn levels varied from 7.02 to 19.75 µg/g-ww, and **El-Moselhy *et al.* (2014)**, whose findings varied from 2.70 to 8.23 µg/g-ww in 14 species. Similarly, **Zaghloul *et al.* (2022)** documented Zn levels of 5.90 to 11.9 µg/g-ww, which are significantly below the concentration recorded in the current study. In contrast, the Zn levels from **Mziray** and **Kimirei (2016)**, which varied from 67.8 to 214.6 µg/g-ww, were higher than those recorded in the present study. **Abbas *et al.* (2024)** reported Zn levels between 11.95 and 35.18 µg/g-ww, partially overlapping with the lower end of the present study's findings.

The Mn concentrations in the muscles of the studied species fluctuated between 0.99 and 2.16 µg/g-ww. These outcomes are higher than those described by **El-Moselhy *et al.* (2014)**, **Zaghloul *et al.* (2022)**, and **El-Shorbagy *et al.* (2024) (**0.10-0.93, 0.264-0.897, and 0.50-1.31 µg/g-ww, respectively**)**. In contrast, **Mziray** and **Kimirei (2016)** observed much higher Mn levels, extending from 5.55 to 10.18 µg/g-ww, which stands in stark contrast to the current investigation. **Abbas *et al.* (2024)** mentioned that the Mn levels ranged between 1.27 and 2.50 µg/g-ww, overlapping partially with the present study's range.

The Ni concentrations in the muscles of the studied spp. fluctuated between 0.77 and 1.87 µg/g-ww. These outcomes are within the range described by **El-Shorbagy *et al.* (2024)**, where Ni levels varied from 1.20 to 1.76 µg/g-ww. However, they are slightly below than those found by **Younis *et al.* (2021)**, where Ni levels varied from 3.60 to 19.19 µg/g-ww. These levels were notably higher than those observed by **Mziray** and **Kimirei (2016)** and **Zaghloul *et al.* (2022)** (0.12-0.15 and 0.332-0.585 µg/g-ww, respectively). In contrast, **Abbas *et al.* (2024)** found Ni levels between 1.46 and 4.86 µg/g-ww, which overlaps somewhat with the range observed in the current investigation.

In general, Al has the highest amount at 81.40±3.88 µg/g-ww, while Cd has the lowest at 0.41±0.01 µg/g-ww, according to the analysis of the elements investigated in sigan fish. In descending order, the elements are ranked as follows: aluminium > iron > zinc > boron > copper > lead > manganese > chromium > nickel > arsenic > barium > cadmium. However, Al in bongus fish exhibited the maximum level at 76.51±6.28 µg/g-ww, while Cd exhibited the minimum at 0.50±0.01 µg/g-ww (aluminium > iron > zinc > boron > copper > arsenic > lead > chromium > manganese > barium > nickel > cadmium). Moreover, the maximum level of trace elements in the harid fish (63.95±3.23 µg/g-ww) was recorded for Al, while Cr exhibits the minimum (0.60±0.03 µg/g-ww) as the descending order of aluminium > boron > iron > copper > zinc > arsenic > lead > manganese > nickel > barium > cadmium > chromium. Statistically, the significant differences between species based on the studied elements were shown ($P<0.05$, one-way ANOVA).

Overall, it emerged that the amounts of copper, iron, nickel, and manganese in all studied marine fish were lower than the **FAO**'s **(1983)** allowable threshold. In contrast, Pb and Zn were below the allowable threshold for all species except sigan fish. All the studied species have levels that surpass the permissible limit. Lastly, all studied species had cadmium levels above the allowable threshold, with the exception of sigan fish (Table 3).

Table 3. Fish muscles' maximum allowable limit (MPL) for trace elements (µg/g wet weight) in accordance with international regulations

	Non-essential elements				Essential elements				
	As	**Pb**	**Cr**	**Cd**	**Cu**	**Fe**	**Zn**	**Mn**	**Ni**
FAO (1983)	1	0.5	2	0.05	30		30		
FAO/WHO (1989)		0.5		0.5	3		40		
WHO (1989)		2		1	30	100	100	1	
USEPA (2000)									2
EU (2015)		0.3		0.25	20		50		80

Table 4. The levels of trace elements (µg/g-ww-b) in the fish species under study from various studies

		Non-essential elements						Essential elements					
		As	**Al**	**Ba**	**Pb**	**Cr**	**Cd**	**Cu**	**Fe**	**B**	**Zn**	**Mn**	**Ni**
Current study	Sigan fish	1.44 ±0.34 ^{c}	81.40±3.88 ^{a}	1.44±0.33 ^{a}	2.18±0.76 ^{a}	1.90±0.87 ^{a}	0.41±0.01 ^{c}	21.84±1.43 ^{a}	63.96±9.22 ^{a}	28.90±1.52	49.69±2.11 ^{a}	2.16±0.91 ^{a}	1.87±0.06 ^{a}
	Bongus fish	3.53 ±0.93 ^{a}	76.51±6.28 ^{b}	0.99±0.03 ^{c}	1.38±0.81 ^{c}	1.18±0.45 ^{b}	0.50±0.01 ^{b}	10.96±1.23 ^{c}	40.64±4.36 ^{b}	33.20±1.78 ^{b}	35.96±1.23 ^{b}	0.99±0.08 ^{c}	0.77±0.04 ^{c}
	Harid fish	2.77 ±0.30 ^{b}	63.95±3.23 ^{c}	1.00±0.09 ^{b}	1.72±0.94 ^{b}	0.60±0.03 ^{c}	1.00±0.01 ^{a}	17.74±1.07 ^{b}	31.26±2.32	45.95±2.48 ^{a}	22.98±1.65 ^{c}	1.26±0.04 ^{b}	1.24±0.06 ^{b}
El-Shorbagy *et al.* (2024)		0.48-5.10	1.93-4.36		2.12-6.83	1.97-5.25	ND	2.11-10.29	31.80-81.35	7.02-19.75		0.50-1.31	1.20-1.76
El-Moselhy *et al.* (2014)		--	--		0.25-0.50	--	0.04-0.380	0.170-0.740	1.15- 10.9	2.70- 8.23		0.10-0.93	--
Yakamercan *et al.* (2021)		--	--		0.72-4.26	--	--	0.07-0.77	--	0.01-0.66		--	0.55-1.96
Younis *et al.* (2021)*		--	--		0.15-0.17	7.63-23.6	--	1.60-3.94	17.0-39.29	--		0.65-1.13	3.60-19.19
Hilal and **Ismail (2008)***		--	--		0.31-1.73	0.21-2.08	--	0.10-0.42	0.52-4.27	0.52-7.29		0.10-0.69	0.21-1.04
Hossain *et al.* (2022)*		--	--		0.74-1.49	--	--	0.61-3.10	--	5.78-9.56		--	0.004-0.17
Al-Amri *et al.* (2021)*		0.002 -0.02	--		0.00-2.75	0.01-0.02	--	0.09-1.31	6.84-20.81	0.94-1.34		--	0.00-1.29
Mziray *et al.* (2016)		3.43-18.52	19.44-87		0.05-0.14	0.10-0.29	--	1.65-4.71	34.02-103.29	67.8-214.6		5.55-10.18	0.12-0.15
Zaghloul *et al*. (2022)		--	--		0.26-1.04	--	0.54-1.09	0.381-0.970	13.6- 29.1	5.90- 11.9		0.264-0.897	0.332-0.585
Hussein *et al.* (2023)		1.03–1.13	1.38-2.11		0.06 -0.17	--	0.03-0.11	--	--	--		--	--
El-Kady *et al.* (2025)		0.15-3.38	1.13-3.44	0.180-0.35	0.009-0.022	0.067-0.181	0.002-0.0094	0.17 -0.37	4.11- 11.8	--	2.61-7.58	0.10-0.270	32.0- 52.3
Abbas *et al.* (2024)		0.50-3.59	0.80-4.21		0.59-4.81	2.29-5.43	ND	10.33-25.85	36.86-135.96	11.95-35.18	--	1.27-2.50	1.46-4.86

Pearson correlation coefficients

Pearson correlation coefficients based on levels of studied elements in the water and sediment are represented in Fig. (2). In contrast, Pearson coefficients based on levels of studied elements in the sigan fish, bongus fish, and harid fish collected from the Suez Gulf are shown in Fig. (3). It was established to determine if some of the elements under study were correlated with one another based on their levels in the sediment, water, and studied fish from the Suez Gulf. The positive relationships between the studied elements suggest a similar input source to the aquatic ecosystem, whereas the negative relationships suggest a different source. It was believed that heavy metals with high positive relationships came from similar sources, while those with strong negative relationships were thought to come from different sources **(Al-Alimi & Alhudify 2016)**.

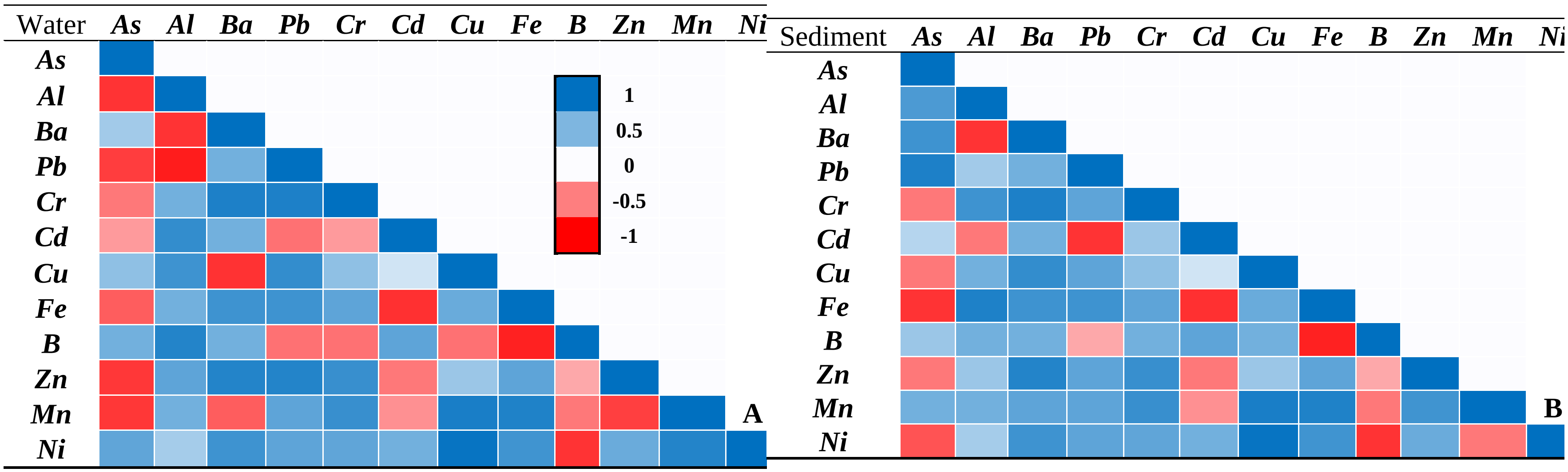

Fig. 2. Pearson correlation coefficients (heatmap) based on the studied elements in the water **(**A**)** and sediment **(**B**)** collected from the Suez Gulf

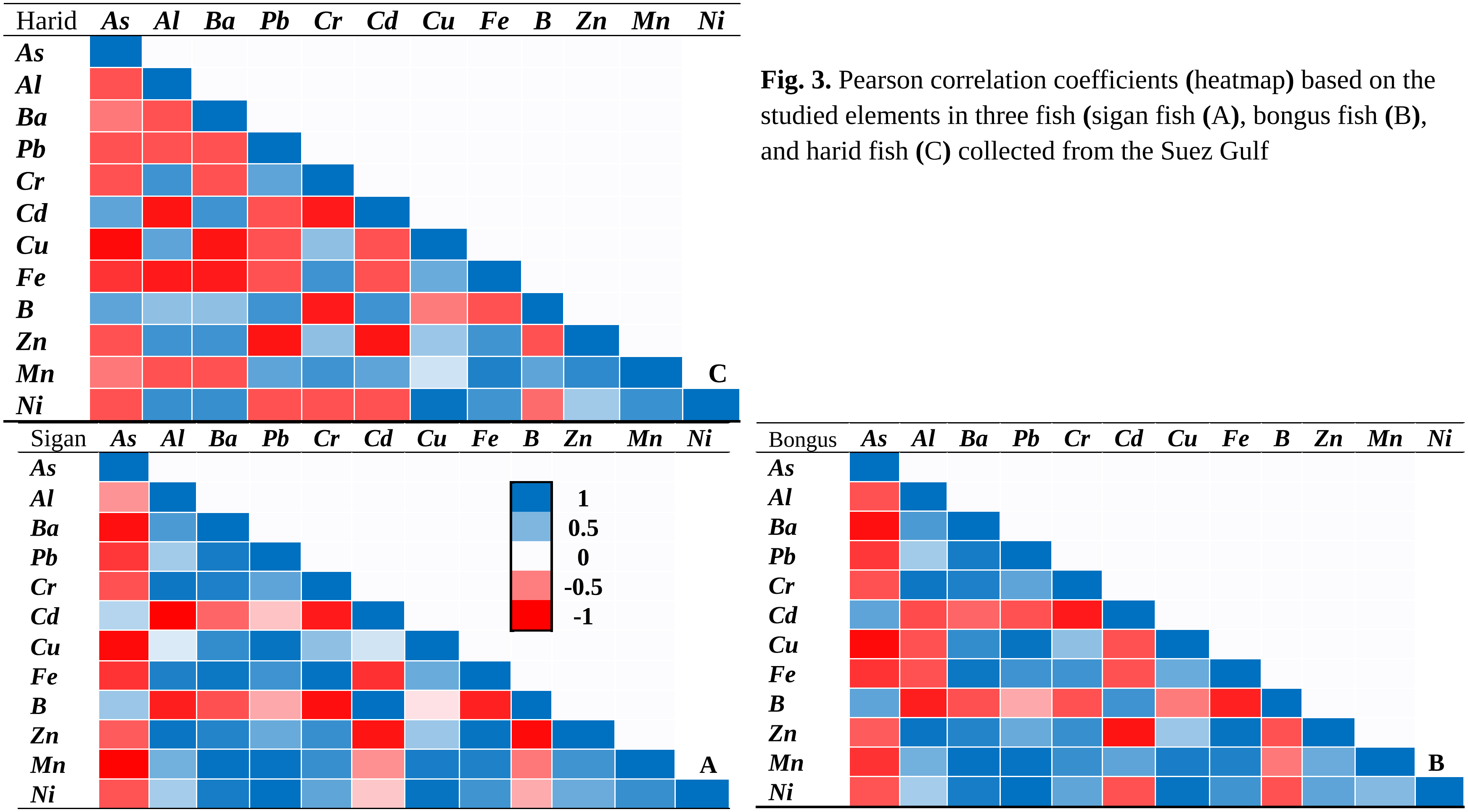

Fig. 3. Pearson correlation coefficients **(**heatmap**)** based on the studied elements in three fish **(**sigan fish **(**A**)**, bongus fish **(**B**)**, and harid fish **(**C**)** collected from the Suez Gulf

Environmental risk assessment

Contamination degree (CD) values

The degree of trace element contamination in various organs of fish was assessed using the contamination degree and metal pollution index **(Tahity *et al.*, 2022)**. The contamination degree (CD) values were calculated based on the levels of Fe, Cr, As, Cu, Pb, Ni, and Mn in the studied species (Fig. 4). With CD values < 1, the levels of contamination for Fe, Cr, Cu, Pb, Ni, and Mn were found to be low, suggesting that all studied species had very little contamination. The contamination degree for As varied across species, with sigan fish showing a low contamination level (CD-As = 1.44), harid fish exhibiting a moderate contamination level (CD-As = 2.77), and bongus fish having detected a high contamination level (CD-As > 3). The contamination degree for Pb and Zn was also generally low, with CD values of less than 1, except for sigan fish, which showed a low contamination degree (1.09 and 1.24, respectively).

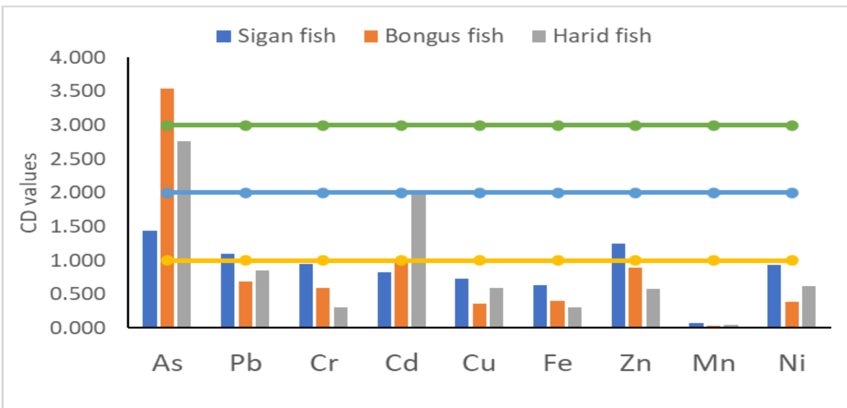

Fig. 4. The contamination factor (CD) values of 9 metals in three marine fish (sigan fish, bongus fish, and harid fish) collected from Suez Gulf

Metal pollution index (MPI) values

The MPI values, which incorporate 12 elements in the studied muscles (Fig. 5). The studied species arranged according to their MPI values as follows: sigan fish (6.03) > harid fish (4.84) > bongus fish (4.59). Low metabolic activity and low amounts of metal-binding proteins in muscles may be related to low MPI values **(Abdel-Khalek *et al.*, 2020; Tashi *et al.*, 2022)**. The MPI value of *Argyrosomus regius* is 0.1 **(Elaarabi *et al.*, 2022)**; sardines and anchovies are 0.46 to 0.76 and 0.65 to 0.89, respectively **(Sofoulaki *et al.*, 2019)**; and demersal and pelagic fish are 3.65 and 4.70, respectively **(Ahmed *et al.*, 2019)**. **Haseeb-ur-Rehman *et al.* (2023)** revealed that the lowest value of MPI from samples collected from Pakistan was 0.62 in *Sepia recurvirostra* and *Cynoglossus bilineatus* while the highest value was 2.78 in *Penaeus monodon*. In fish samples from Bangladesh, however, the MPI value reported in *Systomus sarana* was lower than 1 **(Pinkey *et al.*, 2024)**. However, all studied fish were benthic fish. Compared to pelagic fish, benthic fish species generally exhibit higher concentrations of heavy metals because they are exposed to sediments more frequently and consume more metals through their diet **(Zhao *et al.*, 2012)**. Moreover, a greater MPI value in the studied muscles suggests a clear tendency to accumulate notable quantities of various elements **(Jamil *et al.*, 2014)**.

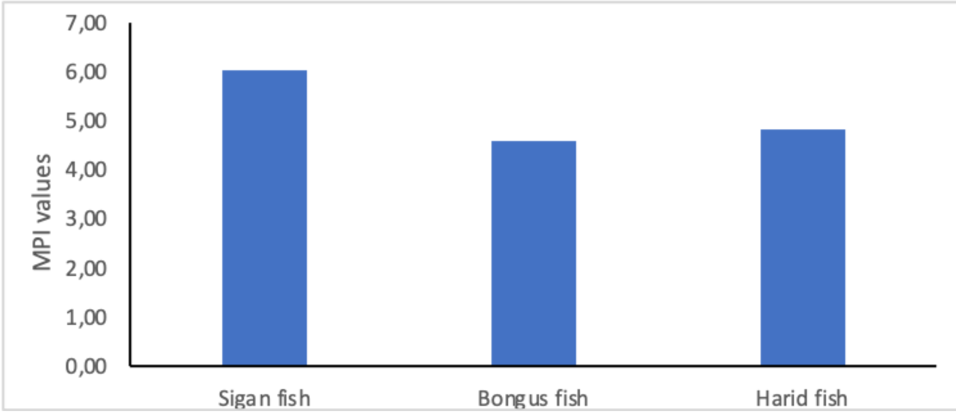

Fig. 5. The element pollution index (MPI) values of the studied metals in three marine fish (sigan fish, bongus fish, and harid fish) collected from Suez Gulf

Health risk Assessment

Estimated daily intake (EDI) values

The oral reference dose for a particular chemical, which describes daily exposure to hazardous compounds to prevent any negative effects on the health of humans over a lifetime **(USEPA 2014, Baki *et al.*, 2018)**, was used to determine the EDI values (Table 5). The analysis of Ba, As, Cr, Al, Pb, and Cd (non-essential elements) in fish consumption reveals that the values of EDI are significantly lower than the Permissible Tolerable Daily Intake (PTDI) values recommended by the FAO/WHO guidelines. For EDI-As, the values range from 1.3E-03 to 3.2E-03 µg/g/day for children and from 8.5E-04 to 2.1E-03 µg/g/day for adults, compared to a PTDI of 2E+00 µg/g/day. EDI-Al has an EDI range of 5.8E-02 to 7.3E-02 µg/g/day for children and 3.7E-02 to 4.8E-02 µg/g/day for adults. Similarly, EDI-Ba shows values of 8.9E-04 to 1.3E-03 µg/g/day for children and 5.8E-04 to 8.5E-04 µg/g/day for adults.

EDI-Pb ranges from 1.2E-03 to 2.0E-03 µg/g/day for children and 8.1E-04 to 1.3E-03 µg/g/day for adults, while EDI-Cr has a range of 5.4E-04 to 1.7E-03 µg/g/day for children and 3.5E-04 to 1.1E-03 µg/g/day for adults. Lastly, EDI-Cd exhibits values between 3.7E-04 and 9.0E-04 µg/g/day for children and 2.4E-04 to 5.9E-04 µg/g/day for adults. For Fe, B, Cu, Mn, Zn, and Ni **(**essential elements**)**, a similar trend is observed, with EDI values consistently below the PTDI limits. EDI-Cu has a value range of 9.9E-03 to 2.0E-02 µg/g/day for children and 6.4E-03 to 1.3E-02 µg/g/day for adults, compared to a PTDI of 5E+01 µg/g/day. EDI-Fe ranges from 2.8E-02 to 5.8E-02 µg/g/day for children and 1.8E-02 to 3.7E-02 µg/g/day for adults, while EDI-B shows values of 2.6E-02 to 4.1E-02 µg/g/day for children and 1.7E-02 to 2.7E-02 µg/g/day for adults. EDI-Zn ranges from 2.1E-02 to 4.5E-02 µg/g/day for children and 1.3E-02 to 2.9E-02 µg/g/day for adults, and EDI-Mn ranges from 8.9E-04 to 1.9E-03 µg/g/day for children and 5.8E-04 to 1.3E-03 µg/g/day for adults. Finally, EDI-Ni shows values of

6.9E-04 to 1.7E-03 µg/g/day for children and 4.5E-04 to 1.1E-03 µg/g/day for adults. Generally, children's consumers often had higher EDI values for all studied elements than adult consumers. Similar findings were conducted by previous studies **(Chai *et al.*, 2015; Saha *et al.*, 2016; Tytła & Widziewicz-Rzońca 2023; El-Shorbagy *et al.*, 2024)**. Furthermore, the EDI values for all essential and non-essential elements are significantly lower than their respective PTDI values, confirming the safety of fish consumption for studied consumers.

Target hazard quotient (THQ) values

The values of THQ in Table (5) for non-essential elements (As, Al, Ba, Pb, Cr, and Cd) across different fish species (sigan fish, bongus fish, and harid fish) demonstrate potential health risks when compared to the permissible threshold level of one, according to **USEPA (2018)**. For THQ-As, values range from 2.8E-01 to 1.1E+00, exceeding the threshold in bongus fish for both children (1.1E+00). THQ-Al shows lower values, extending from 3.7E-02 to 7.3E-02 for children and 2.9E-03 to 4.8E-02 for adults. For THQ-Ba, the values ranged between 4.5E-03 and 6.5E-03 for children and 2.9E-03 to 4.2E-03 for adults. However, THQ-Pb poses a concern, with values reaching 5.5E-01 in sigan fish for children and 3.6E-01 for adults. THQ-Cd shows a significant variation, with values reaching 9.0E-01 for children and 5.9E-01 for adults in harid fish. For essential elements (Cu, Fe, B, Zn, Mn, and Ni), the THQ values generally fall below the allowable threshold, indicating minimal health risks.

THQ-Cu exhibits values extending from 2.5E-01 to 4.9E-01 for children and 1.6E-01 to 3.2E-01 for adults. THQ-Fe and THQ-B show low THQ values, with THQ-Fe extending from 4.0E-02 to 8.2E-02 for children and 2.6E-02 to 5.4E-02 for adults, while THQ-B values range from 1.5E-01 to 2.4E-01 for children and 1.0E-01 to 1.6E-01 for adults. THQ-Zn ranges from 6.9E-02 to 1.5E-01 for children and 4.5E-02 to 9.7E-02 for adults. Ni values range from 3.5E-02 to 8.4E-02 for children and 2.3E-02 to 5.5E-02 for adults. Generally, the THQ values for all essential and non-essential elements are all within safe limits except for As, which exceeds the threshold in bongus fish for both children (1.1E+00). Nevertheless, the higher values of THQ for children compared to adults underscore the need for continuous monitoring of trace element accumulation in the studied fish. These results are similar to those found in other studies **(Kumari *et al.*, 2018; Hossain *et al.*, 2022; Abbas *et al.*, 2024; Yin *et al.*, 2024)**.

Hazard index (HI) values

The values of the HI for studied elements in the muscles of three marine spp. are illustrated in Fig. (6). The HI values for adults and children who consumed the studied marine fish were assessed based on the THQ values; the impacts on individuals would be adverse **(**HI ≤ 1.0E+00**)**; HI > 1.0E+00 most probably had a detrimental effect; and HI > 10.0E+00 was severe or chronic with acute consequences, as advised by **Lei *et al.* (2015)**.

The values of HI for children and adults consuming sigan fish, bongus fish, and harid fish highlight potential health risks due to cumulative exposure to trace elements.

For children, the HI values exceeded the permissible limit (1.0E+00), with values extending from 2.90E+00 in bongus fish to 3.20E+00 in harid fish and 3.00E+00 in sigan fish. These elevated values indicate probable negative health impacts, highlighting the increased susceptibility of children to the combined adverse effects of trace elements in studied fish. Similarly, for adults, the HI values also surpassed the acceptable threshold, extending from 1.90E+00 in sigan fish and bongus fish to 2.10E+00 in harid fish. While these outcomes were lower than those observed in children, they still represent a significant risk of adverse health effects for adult consumers. These results highlight how crucial stringent monitoring and regulatory measures are to control metal levels in fish, thereby reducing potential health hazards for studied consumers.

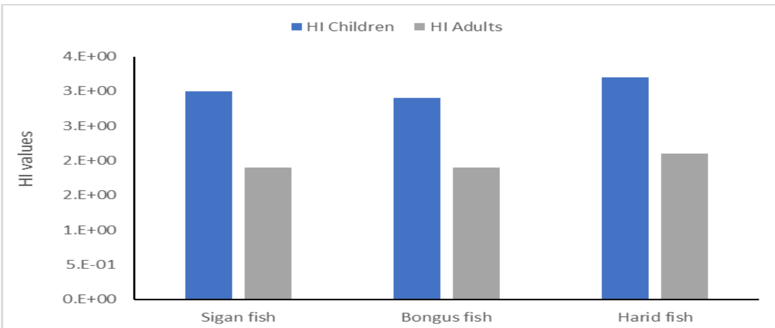

Fig. 6. HI values in three marine fish (sigan fish, bongus fish, and harid fish) collected from Suez Gulf

Carcinogenic risk values

The cancer risk (CR) results for non-essential trace elements in five species under study are shown in Fig. (7). Significant exposure to metals is indicated by CR values; acceptable exposure values (CR values < 1E-06), tolerable exposure values (1E-06-1E-04), and severe exposure values > 1E-04 **(Baki *et al.*, 2018; USEPA, 2018)**. The CR values for Cr, Pb, Ni, Cd, and As in the marine fish were recorded for both eaters (children and adults). The carcinogenic risk (CR) values for various metals (lead, arsenic, and cadmium) in the sigan fish, bongus fish, and harid fish show varying risks for children and adults. For cadmium, the CR values for children range from 1.41E-06 in sigan fish to 3.42E-06 in harid fish, and for adults, they range from 9.12E-07 in sigan fish to 2.24E-06 in harid fish, all of which fall within the acceptable range (1E-06-1E-04), indicating minimal carcinogenic risk. However, the CR-lead values range from 1.02E-05 in bongus fish to 1.70E-05 in sigan fish for children and from 6.89E-06 in bongus fish to 1.11E-05 in sigan fish for adults, all of which fall below the unacceptable threshold of 1E-04, suggesting minimal carcinogenic risk. Moreover, for arsenic, the CR values for children range from 1.95E-03 in sigan fish to 4.80E-03 in bongus fish, and for adults, they range from 1.28E-03 in sigan fish to 3.15E-03 in bongus fish, all of which fall well above the permissible level of 1E-04, suggesting a significant carcinogenic risk for the studied consumers.

Table 5. The values of EDI and THQ in three marine fish **(**sigan fish, bongus fish, and harid fish**)** collected from Suez Gulf

		As		Al		Ba		Pb		Cr		Cd	
Non-essential elements		Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
	Sigan fish	1.30E-03	8.50E-04	7.30E-02	4.80E-02	1.30E-03	8.50E-04	2.00E-03	1.30E-03	1.70E-03	1.10E-03	3.70E-04	2.40E-04
EDI	**Bongus fish**	3.20E-03	2.10E-03	6.90E-02	4.50E-02	8.90E-04	5.80E-04	1.20E-03	8.10E-04	1.10E-03	6.90E-04	4.50E-04	2.90E-04
	Harid fish	2.50E-03	1.60E-03	5.80E-02	3.70E-02	9.00E-04	5.90E-04	1.50E-03	1.00E-03	5.40E-04	3.50E-04	9.00E-04	5.90E-04
	Sigan fish	4.30E-01	2.80E-01	7.30E-02	4.80E-02	6.50E-03	4.20E-03	5.50E-01	3.60E-01	5.70E-01	3.70E-01	3.70E-01	2.40E-01
THQ	**Bongus fish**	1.10E+00	6.90E-01	6.90E-02	4.50E-02	4.50E-03	2.90E-03	3.50E-01	2.30E-01	3.50E-01	2.30E-01	4.50E-01	2.90E-01
	Harid fish	8.30E-01	5.40E-01	5.80E-02	3.70E-02	4.50E-03	2.90E-03	4.30E-01	2.80E-01	1.80E-01	1.20E-01	9.00E-01	5.90E-01
PTDI values		2E+00						3.00E-02		2.00E-01		3.00E-03	

Essential elements		Cu		Fe		B		Zn		Mn		Ni	
		Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults	Children	Adults
	Sigan fish	2.00E-02	1.30E-02	5.80E-02	3.70E-02	2.60E-02	1.70E-02	4.50E-02	2.90E-02	1.90E-03	1.30E-03	1.70E-03	1.10E-03
EDI	**Bongus fish**	9.90E-03	6.40E-03	3.70E-02	2.40E-02	3.00E-02	1.90E-02	3.20E-02	2.10E-02	8.90E-04	5.80E-04	6.90E-04	4.50E-04
	Harid fish	1.60E-02	1.00E-02	2.80E-02	1.80E-02	4.10E-02	2.70E-02	2.10E-02	1.30E-02	1.10E-03	7.40E-04	1.10E-03	7.30E-04
	Sigan fish	4.90E-01	3.20E-01	8.20E-02	5.40E-02	1.50E-01	1.00E-01	1.50E-01	9.70E-02	1.40E-02	9.00E-03	8.40E-02	5.50E-02
THQ	**Bongus fish**	2.50E-01	1.60E-01	5.20E-02	3.40E-02	1.80E-01	1.10E-01	1.10E-01	7.00E-02	6.40E-03	4.10E-03	3.50E-02	2.30E-02
	Harid fish	4.00E-01	2.60E-01	4.00E-02	2.60E-02	2.40E-01	1.60E-01	6.90E-02	4.50E-02	8.10E-03	5.30E-03	5.60E-02	3.60E-02
PTDI values		5.00E+01		7.00E+01				5.00E+01		1.40E+02		4.00E-02	

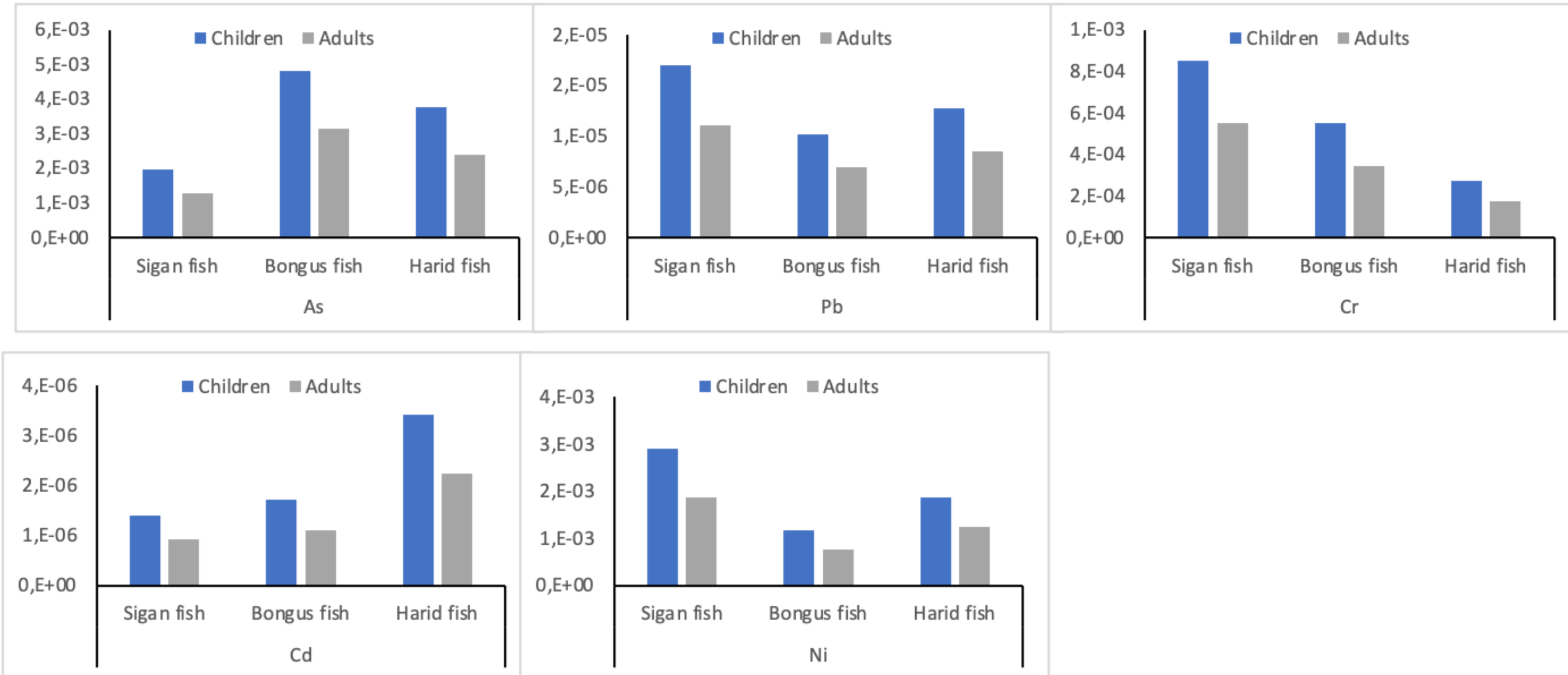

Fig. 7. CR values in three marine fish (sigan fish, bongus fish, and harid fish) collected from Suez Gulf

CONCLUSION

The current study highlights the ecological and health hazards associated with these contaminants and offers important insights into the accumulation and distribution of trace elements in sediments, water, and fish species from the Gulf of Suez. The highest element of water samples was reported for iron, while the lowest element was recorded for copper. However, the maximum values of the studied element in the sediment samples were reported for boron, and the minimum values were detected for zinc. Moreover, the levels of essential elements (Zn, Fe, and Cu) in the examined fish muscles were found to be within permissible limits; non-essential elements, particularly As and Cd, exceeded safe levels, thereby raising concerns regarding potential health risks. The bioaccumulation patterns of elements in fish tissues suggest that certain species, especially sigan fish, exhibit lower levels of metal accumulation, making them safer for consumption compared to others like bongus fish and harid fish. The EDI values for both consumers remain below the tolerable limits, indicating that the fish from the Gulf of Suez can be considered safe for consumption in terms of essential elements. However, the THQ analysis further underscores the potential risks of eating fish with high amounts of As, particularly for vulnerable populations. To mitigate these risks, further monitoring and management strategies are necessary to reduce trace element pollution in aquatic environments and guarantee that marine spp. are safe for human intake.

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