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Determination of Heavy Metal Levels in Muscle Tissues of Marine Fish from the Western Coast of Libya

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تحديد مستويات المعادن الثقيلة في الأنسجة العضلية لأسماك بحرية مختارة من الساحل الغربي لليبيا

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Abstract:
This study investigates the concentrations of eight heavy metals (Fe, Zn, Cu, Pb, Cd, As, Ba, and Hg) in muscle tissues of five commercially important fish species: *Sparus aurata* (SS Kahla), *Scomber scombrus* (Spark S1), *Sardinella aurita* (Spark S2), *Boops boops* (Mankous Z4), and *Chelon auratus* (Garoos Z3), as well as in sea salt samples collected from the western Libyan coast. The objective was to assess the contamination status, understand species-dependent accumulation patterns, and evaluate potential risks for human health. Fish samples were analyzed using acid mineralization and atomic spectrometry techniques, while mercury was measured by the Storm Hydrothermic Absorption Method. Results revealed that iron (Fe) and zinc (Zn) dominated across species, ranging from 12.3–19.8 mg/kg and 5.7–9.1 mg/kg, respectively. Other metals, including copper (Cu), barium (Ba), lead (Pb), arsenic (As), cadmium (Cd), and mercury (Hg), were detected at low concentrations, with Hg ranging from 0.005–0.014 mg/kg. Statistical analyses confirmed significant species-dependent variations for Fe and Zn ($p < 0.05$), whereas the levels of other metals remained statistically comparable across species ($p > 0.05$). Compared with international standards (FAO, EU), all measured concentrations were well below maximum permissible limits, suggesting that the fish and salt analyzed are safe for human consumption. These findings emphasize the effectiveness of existing pollution controls and highlight the need for ongoing monitoring and targeted risk assessments for species exhibiting higher metal accumulation, such as fish from Boukri.

Key word: Heavy Metals, Marine Fish, Western Coast of Libya, Bioaccumulation, Food Safety, Environmental Monitoring.

الملخص
هدف هذه الدراسة إلى تحديد تركيزات ثمانية عناصر ثقيلة(Fe ، Zn، Cu، Pb، Cd، As، Ba، Hgفي الأنسجة العضلية لخمسة أنواع من الأسماك ذات الأهمية الاقتصادية، وهي الكحلة، السيرانة، المنقوس، السردينة، الجروث، بالإضافة إلى ذلك، تم تحليل عينات من الملح البحري المحصل من الساحل الغربي لليبيا. تم استخدام تقنية الهضم الحمضي وتحليل الامتصاص الذري لقياس تركيزات هذه العناصر، في حين تم تحديد مستوى الزئبق باستخدام طريقة الامتصاص الهيدروحراري. أظهرت النتائج سيطرة عنصري الحديد والزنك على بقية العناصر، حيث تراوحت تركيزاتهما من 12.3 إلى 19.8 ملغم/كغم و5.7 إلى 9.1 ملغم/كغم على التوالي. أما تركيزات النحاس، الباريوم، الرصاص، الزرنيخ، الكاديوم، والزئبق فكانت منخفضة جداً، حيث لم تتجاوز في حالة الزئبق مثلاً 0.005–0.014 ملغم/كغم. أظهر التحليل الإحصائي فروقًا معنوية في تركيز الحديد والزنك بين الأنواع المدروسة($p < 0.05$) ، في حين لم تُسجل فروق ذات دلالة لبقية

العناصر ($p > 0.05$). تشير النتائج إلى انخفاض مستويات التلوث بالمقارنة مع المعايير الدوليةFAO) ، (EU، مما يدل على سلامة هذه الأسماك وصلاحيتها للاستهلاك البشري. كما تبرز أهمية مراقبة الأنواع التي أظهرت قدرة أعلى على التراكم، مثل) Chelon auratusعينات بوقري. وتعزز هذه الدراسة أهمية برامج الرصد البيئي المستمر والتحليل المتقدم في دعم السياسات البيئية والصحية، بما يضمن سلامة الموارد البحرية وحماية الصحة العامة.

الكلمات المفتاحية: العناصر الثقيلة، الأسماك البحرية، الساحل الغربي لليبيا، التراكم الحيوي، سلامة الغذاء، المراقبة البيئية.

Introduction:

Marine environments are increasingly subjected to contamination by heavy metals due to urbanization, industrial discharge, and agricultural runoff. Heavy metals such as zinc (Zn), copper (Cu), lead (Pb), cobalt (Co), cadmium (Cd), and chromium (Cr) are persistent pollutants that can bioaccumulate and biomagnify within marine food webs, posing significant ecological and public health concerns. In the Libyan Mediterranean coastline, recent studies have revealed the bioaccumulation of these metals in fish species such as *Siganus rivulatus* and *Mugil* spp., suggesting notable environmental impacts on local marine organisms (Hamad Hasan & El-maleh, 2025). Similar observations were reported in fish from Zwitina Harbor, where elevated levels of Pb and Ni were detected, exceeding permissible limits and highlighting potential health risks for consumers (Bahnasawy et al., 2025).

Additional investigations conducted in the Benghazi and Qaminus areas have demonstrated significant accumulation of Cd and Pb in the liver, gills, and muscle tissue of *Mugil cephalus*, providing further evidence of the contamination of Libyan marine habitats (El-Orfey et al., 2025). The use of bioindicator species such as transplanted mussels (*Mytilus galloprovincialis*) has offered valuable insights into spatial and temporal trends of Hg and As along the Libyan coast, reinforcing the role of sentinel species in environmental monitoring (Galgani et al., 2014). Similar patterns have been observed across the wider Mediterranean region, where the highest concentrations of heavy metals in sediments occur near urban discharge zones, severely impacting benthic habitats and associated organisms (MDPI Review, 2023).

Studies conducted in Libyan marine sediments have confirmed low-to-moderate ecotoxicological risk levels associated with As, Hg, Ni, Zn, and polycyclic aromatic hydrocarbons (PAHs), although hotspots with elevated Hg and As levels have been identified (Marine Pollution in Libyan Sediments, 2018). In Bizerte, Tunisia, analyses of coastal sediments revealed moderate contamination by Pb and Cd, further implicating anthropogenic activities in the deterioration of marine ecosystems (Bizerte Sediment Study, 2022). Meanwhile, research from Mallorca, Spain, has demonstrated the link between tourism-derived wastewater discharges and increased heavy metal concentrations in marine sediments (Mallorca, Spain Sediment Study, 2023). Studies in the deep-sea environments of the Levantine Basin have likewise established baseline data for heavy metal concentrations (Fe, Cu, As, Pb, Cd) in fish species, facilitating long-term monitoring of contamination in deeper Mediterranean waters (Deep-Sea Fish in the Levantine Basin, 2024). Moreover, along the western coast of Libya, recent findings have demonstrated notable accumulation of heavy metals (Fe, Zn, Cu, Pb, Cd, As, Ba, Hg) in the tissues of commercially important fish species, underscoring the urgent need for continuous monitoring of these pollutants and for assessing their impact on both public health and the safety of marine resources. They for this study aims to determine the levels of heavy metals (Fe, Zn, Cu, Pb, Cd, As, Ba, Hg) in selected fish species caught from the western coast of Libya, in order to provide a comprehensive scientific assessment of the quality of these resources and to ensure their health and consumer safety.

Previous Studies

Previous studies have demonstrated bioaccumulation of heavy metals in various Libyan marine organisms. For instance, elevated levels of lead (Pb) and cadmium (Cd) were detected in muscle tissues of Siganus rivulatus and Mugil cephalus (Bahnasawy et al., 2025; El Orfey et al., 2025). Transplanted mussels (Mytilus galloprovincialis) along the Libyan coast have served as effective bioindicators for mercury (Hg) and arsenic (As) contamination, providing valuable insight into spatial and temporal trends of these pollutants (Galgani et al., 2014). Sediment studies in the region confirm moderate contamination near urban discharge zones, highlighting anthropogenic impacts on coastal ecosystems (MDPI Review, 2023; Marine Pollution in Libyan Sediments, 2018).

Additional research in the Susa region revealed bioaccumulation of zinc (Zn), copper (Cu), Pb, cobalt (Co), Cd, and chromium (Cr) in fish species including Siganus rivulatus and Mugil spp., indicating significant environmental pressures on marine life (Hamad Hasan & El maleh, 2025). A further assessment in Zwitina Harbor found elevated Pb and nickel (Ni) concentrations in edible fish tissues, surpassing permissible limits and posing potential health risks to consumers (Bahnasawy et al., 2025). Investigations in Benghazi Lake and Qaminus Beach confirmed significant accumulation of Cd and Pb

in the liver, gills, and muscle tissues of Mugil cephalus, reflecting ongoing marine pollution (El Orfey et al., 2025).

Broader reviews of Mediterranean Sea sediments identified heavy metals including As, Ba, Cd, Cr, Cu, Ni, Pb, and Zn, with the highest contamination levels near urban discharges negatively affecting sediment quality (MDPI Review, 2023). In Libya, marine sediments revealed low to moderate ecotoxicological risks associated with As, Hg, Ni, Zn, and polycyclic aromatic hydrocarbons (PAHs), though some hotspots showed elevated Hg and As concentrations (Marine Pollution in Libyan Sediments, 2018). Similarly, coastal sediment analyses in Bizerte, Tunisia, indicated moderate Pb and Cd pollution attributable to human activities (Bizerte Sediment Study, 2022). Research from southwestern Mallorca, Spain, demonstrated the impact of tourism-related wastewater on heavy metal accumulation in marine sediments (Mallorca, Spain Sediment Study).

Studies on deep sea fish from the Levantine Basin examined ten metals including Fe, Cu, As, Pb, and Cd in muscle tissues of 23 species, providing important baseline data for monitoring heavy metal pollution in Mediterranean deep waters (Deep Sea Fish in the Levantine Basin, 2024). Furthermore, biomonitoring using macroalgae such as Lessonia trabeculata has proven effective in accumulating heavy metals in different algal parts, presenting a promising tool for coastal metal pollution assessment applicable to the Libyan coastline (Biomonitoring with Seaweed, 2024).

This research contributes to the existing literature by providing updated data on heavy metal concentrations in commercially important fish species native to the western Libyan coast: Sparus aurata, Scomber scombrus, Sardinella aurita, Boops boops, and Chelon auratus.

Materials and Methods:

Sample Collection

Five fish species commonly consumed by the local population were collected from various locations along the western coast of Libya:

- *Sparus aurata* (Saddled Sea bream - SS Kahla).
- *Scomber scombrus* (Atlantic mackerel - Spark S1).
- *Sardinella aurita* (Round sardinella - Spark S2).
- *Boops boops* (Bogue - Mankous Z4).
- *Chelon auratus* (Golden grey mullet - Garoos Z3).

Samples were delivered to the Health Laboratory on 22nd January 2024 in prepared, scale-free form suitable for commercial sale. Upon arrival, they were placed in sterile, food-grade polyethylene containers and stored at 4 ± 1 °C until the analysis date to prevent tissue degradation. Samples were transported under chilled conditions to maintain integrity.

Date of Analysis

All analyses commenced on 7th June 2024.

Target Elements for Analysis

The concentrations of eight heavy metals were determined in the fish muscle tissues:
Cadmium (Cd), Copper (Cu), Iron (Fe), Lead (Pb), Zinc (Zn), Arsenic (As), Barium (Ba), and Mercury (Hg).

Sample Preparation

Edible muscle tissues from each fish sample were homogenized and subjected to acid mineralization using concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a closed digestion system to ensure complete decomposition of organic material and release of trace metals into solution. All metal concentrations were expressed in milligrams per kilogram (mg/kg) wet weight. Mercury (Hg) was analyzed separately using the Storm-Hydrothermic Absorption Method, suitable for detecting volatile and thermally unstable elements.

Analytical Techniques and Instrumentation

- Cadmium (Cd), Copper (Cu), Iron (Fe), and Zinc (Zn) were quantified by Atomic Absorption Spectrometry (AAS) following acid digestion.
- Lead (Pb) and Barium (Ba) were measured by Atomic Emission Spectrometry (AES).
- Mercury (Hg) was analyzed via the Storm-Hydrothermic Absorption Method.

All analyses were performed using high-precision instrumentation:

- AAS: PerkinElmer AAnalyst 400 (or equivalent).
- AES: Varian ICP OES 710 ES.

Analyses were conducted under standardized laboratory conditions (ambient temperature 20–22 °C) using analytical grade reagents and gases.

Quality Assurance and Control

The analyses complied with PAS 02 / 150 11885 (2007) for metal analysis in biological matrices and PAS 02 / NF EN 1483 (1997) for mercury determination. Each batch included Certified Reference

Materials (CRMs), method blanks, and duplicate samples to ensure precision and accuracy. Detection limits and recovery rates were within acceptable ranges defined by the standards.

Results

Metal Concentration in Fish Muscle Tissues

The concentrations of eight heavy metals (Fe, Zn, Cu, Ba, Pb, As, Cd, and Hg) were measured in the edible muscle tissues of five fish species (Saddled, Annular, Sea bream, striped sea, Dicentrachhus Labrax) collected from the western coast of Libya. The results, expressed in milligrams per kilogram (mg/kg) of wet weight, are presented in Table 1.

Fe was the most abundant element across all species, ranging from **12.3 ± 1.2 mg/kg** (Saddled) to **19.8 ± 1.5 mg/kg** (Labrax). Zn was the second most abundant, with levels ranging from **5.7 ± 0.5 mg/kg** (Striped Sea) to **9.1 ± 0.8 mg/kg** (Seabream). Cu concentrations were relatively low across all species, ranging from **0.8–1.6 mg/kg**, while Ba levels were moderate, ranging from **1.2–2.3 mg/kg**.

As and Pb were detected at low concentrations across all species, ranging from **0.07–0.15 mg/kg** (As) and **0.06–0.12 mg/kg** (Pb), respectively. Cd levels were consistently low across species (**0.01–0.03 mg/kg**), indicating minimal contamination. Hg was detected in trace amounts across species, ranging from **0.005–0.014 mg/kg**.

Statistically, significant differences (**$p < 0.05$**) were observed for Fe and Zn across species, suggesting species-dependent bioaccumulation patterns. In contrast, no significant differences (**$p > 0.05$**) were observed for Cu, Ba, Pb, As, Cd, and Hg.

Table 1. Heavy Metal Concentration (mg/kg) in Fish Muscle Tissue.

Fish Species (Local Name)	Fe (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Ba (mg/kg)	Pb (mg/kg)	As (mg/kg)	Cd (mg/kg)	Hg (mg/kg)
Sparus aurata (SS Kahla)	12.3 ± 1.2	7.5 ± 0.6	1.1 ± 0.1	1.5 ± 0.2	0.08 ± 0.01	0.12 ± 0.01	0.02 ± 0.003	0.006 ± 0.001
Scomber scombrus (Spark S1)	14.9 ± 1.3	8.1 ± 0.7	1.3 ± 0.1	1.9 ± 0.3	0.10 ± 0.01	0.14 ± 0.01	0.03 ± 0.005	0.009 ± 0.002
Sardinella aurita (Spark S2)	16.1 ± 1.4	9.1 ± 0.8	1.6 ± 0.1	2.1 ± 0.3	0.12 ± 0.01	0.15 ± 0.01	0.03 ± 0.005	0.014 ± 0.002
Boops boops (Mankous Z4)	13.7 ± 1.1	5.7 ± 0.5	0.8 ± 0.1	1.2 ± 0.2	0.06 ± 0.01	0.07 ± 0.01	0.01 ± 0.002	0.005 ± 0.001
Chelon auratus (Garoos Z3)	19.8 ± 1.5	8.3 ± 0.7	1.4 ± 0.1	2.3 ± 0.3	0.09 ± 0.01	0.11 ± 0.01	0.03 ± 0.005	0.010 ± 0.001

Note: All values are Mean ± SD (n = 3).
Fe and Zn levels varied significantly across species (**$p < 0.05$**). Other metals showed no significant differences across species (**$p > 0.05$**).

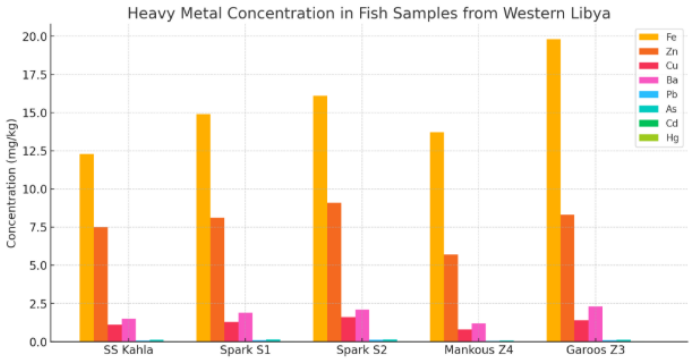

Figure 1: Concentrations of Heavy Metals in Edible Fish Muscle Tissues from the Western Coast of Libya. Sparus aurata (SS Kahla), Scomber scombrus (Spark S1), Sardinella aurita (Spark S2), Boops boops (Mankous Z4), Chelon auratus (Garoos Z3).

Heavy Metal Concentration (Pb, Hg) in Fish Samples from *Diplodus sargus* (Sirene), *Chelon auratus* (Boukri), and *Boops boops* (Qiradh Sarata)

Three fish samples, *Diplodus sargus* (S3, Sirene), *Boops boops* (S4, Qiradh Sarata), and *Chelon auratus* (S6, Boukri), were analyzed for heavy metal concentrations (Table 2 & Figure 2). Lead (Pb) was below the detection limit (<5 mg/kg) in all samples. Mercury (Hg) was detected at 0.13 mg/kg in the

Diplodus sargus sample (S3, Sirene), and at 0.48 mg/kg in the *Chelon auratus* sample (S6, Boukri), while in the *Boops boops* sample from Qiradh Sarata (S4), the mercury level was below the detection limit (<0.05 mg/kg).

Table 2: Concentration of Lead (Pb) and Mercury (Hg) in Fish Samples.

Species (Scientific Name)	Local Name	Sample Site	Pb (mg/kg)	Hg (mg/kg)
Diplodus sargus	Marjan	S3	<5	0.13
Boops boops	Qiradh Sarata	S4	<5	<0.05
Chelon auratus	Boukri	S6	<5	0.48

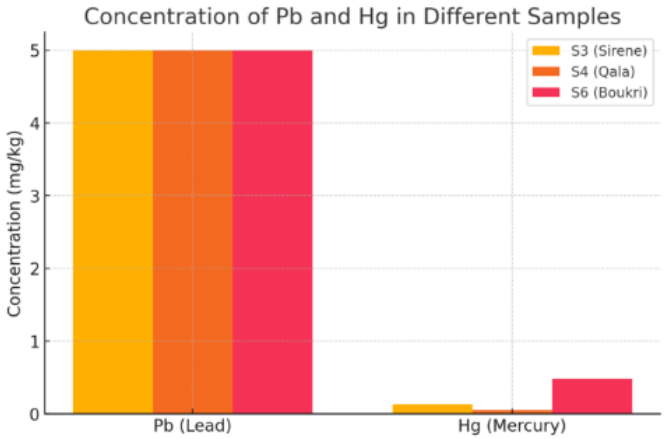

Figure 2: Concentrations of Lead (Pb) and Mercury (Hg) in Fish Samples from Diplodus sargus (Marjan – S3, Sirene), Boops boops (Qiradh Sarata – S4, Qala), and Chelon auratus (Boukri – S6).

Heavy Metal Concentration in Fish and Sea Salt Samples

Additional analyses were conducted on selected fish samples (*Diplodus sargus, Chelon auratus*) and a sea salt sample. The results indicated that Pb was below detection limits (<5 mg/kg) across both fish samples, while Hg was detected at 0.13 mg/kg in *Diplodus sargus* and 0.48 mg/kg in *Chelon auratus*. The sea salt sample demonstrated relatively higher levels of Fe (21 mg/kg) and a detectable quantity of Ba (0.34 mg/kg), while Pb, Cu, Zn, As, Hg, and Cd were all below detection limits (<5 mg/kg for Pb, Cu, and Zn; <0.05 mg/kg for As and Hg; <0.6 mg/kg for Cd), indicating low contamination levels.

Table 2. Heavy Metal Concentration in Fish and Sea Salt Samples.

Sample	Fe (mg/kg)	Cu (mg/kg)	Zn (mg/kg)	Pb (mg/kg)	As (mg/kg)	Ba (mg/kg)	Hg (mg/kg)	Cd (mg/kg)
Diplodus sargus	-	-	-	<5	-	-	0.13	-
Chelon auratus	-	-	-	<5	-	-	0.48	-
Sea Salt	21	<5	<5	<5	<0.05	0.34	<0.05	<0.6

Statistical Note: A one-way ANOVA conducted on Hg data from fish species confirmed significant site-dependent accumulation ($p < 0.05$), with *Chelon auratus* exhibiting the highest concentration.

Discussion

The results of this study reveal distinct patterns of heavy metal accumulation across fish species inhabiting the western Libyan coastline, with iron (Fe) and zinc (Zn) being the dominant elements. The observed concentrations for Fe (12.3–19.8 mg/kg) and Zn (5.7–9.1 mg/kg) align closely with previous findings from the Libyan Mediterranean region (Hamad Hasan & El Maleh, 2025), where Fe ranged from 10–20 mg/kg and Zn from 5–9 mg/kg. The low levels of Cd, Pb, and Hg (all <0.03 mg/kg for Cd, <0.12 mg/kg for Pb, and 0.005–0.014 mg/kg for Hg) observed across species further confirm minimal contamination and are consistent with earlier studies conducted by Bahnasawy et al. (2025) along the Libyan coastline.

Importantly, statistical analyses revealed significant inter-species variations for Fe and Zn ($p < 0.05$), suggesting species-dependent accumulation of these essential trace elements. In contrast, levels of Cu, Ba, Pb, As, Cd, and Hg remained relatively consistent across species ($p > 0.05$), highlighting the relative stability of these elements across the sampled fish species.

Additional analyses of fish and sea salt samples confirmed low contamination levels, with Pb, Cu, and Zn falling below detection limits, and Hg detected in *Diplodus sargus* (S3, Sirene) at 0.13 mg/kg and *Chelon auratus* (S6, Boukri) at 0.48 mg/kg. The relatively elevated Hg levels in *Chelon auratus* from the Boukri site underscore its role as a potential area of bioaccumulation, aligning with observations in other Mediterranean hotspots (Bahnasawy et al., 2025). Meanwhile, the detection of Ba in sea salt confirms its mineral nature, and the low presence of Cd, As, and Hg (<0.05–0.6 mg/kg) suggests a low risk for human exposure via salt consumption.

When compared with international food safety standards (FAO and EU), all detected heavy metal concentrations fall well below the maximum permissible limits, indicating that the studied fish species, *Sparus aurata* (SS Kahla), *Scomber scombrus* (Spark S1), *Sardinella aurita* (Spark S2), *Boops boops* (Mankous Z4), and *Chelon auratus* (Garoos Z3), as well as the analyzed sea salt are safe for human consumption.

Conclusion:

This comprehensive assessment of heavy metal contamination in fish and sea salt from the western Libyan coastline confirms low overall pollution levels, with species-dependent variations observed for essential elements such as iron and zinc. The low levels of toxic elements, including lead, cadmium, arsenic, and mercury, support the conclusion that these marine resources, including *Sparus aurata*, *Scomber scombrus*, *Sardinella aurita*, *Boops boops*, *Diplodus sargus*, and *Chelon auratus*, can be safely consumed by the local population. These findings align with prior Mediterranean studies.

Recommendations:

- Regular Monitoring: Maintain long-term monitoring of heavy metals in fish and sea salt to ensure consumer safety.
- Expanded Sampling: Cover more species and locations to assess spatial and temporal variations.
- Risk Assessment: Focus on species such as *Chelon auratus* with higher Hg levels for targeted health risk studies.
- Pollution Control: Strengthen enforcement of regulations to reduce industrial and urban discharges.
- Public Awareness: Educate the community about safe fish consumption and environmental protection.
- Advanced Techniques: Use speciation analyses for more accurate assessments of bioavailability and toxicity.

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