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Original article

Assessment of Heavy Metal Concentrations (Copper, Cadmium, and Lead) in Tissues and Gills of Mullet Fish (Mugil Spp.) from Sousa Harbor, Libya

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ABSTRACT

Heavy metal contamination in aquatic environments represents a major environmental and public health concern due to the toxic effects of these metals and their ability to bioaccumulate in aquatic organisms. This study aimed to determine the concentrations of copper (Cu), cadmium (Cd), and lead (Pb) in mullet fish (Mugil spp.) collected from Sousa Harbor in eastern Libya. The analysis was conducted on two fish parts: muscle tissue and gills. Fish samples were collected, washed, dried, and subjected to wet digestion using nitric acid, sulfuric acid, and hydrogen peroxide. The concentrations of heavy metals were measured using a Thermo Electron Corporation analytical instrument. Results indicated that the gills accumulated higher concentrations of heavy metals compared with the muscle tissues. The findings highlight the potential risk of heavy metal contamination in the marine environment and emphasize the importance of monitoring heavy metal levels in mullet fish for environmental and human health protection.

Keywords. Heavy metal, Copper, Cadmium, Lead, Tissues, Gills, Mullet.

Introduction

Aquatic environments are increasingly subjected to contamination by heavy metals as a result of rapid industrialization, urbanization, agricultural runoff, and domestic waste discharge. These pollutants, including copper (Cu), cadmium (Cd), and lead (Pb), are of particular concern due to their persistence, non-biodegradable nature, and ability to accumulate in aquatic organisms. Once introduced into water bodies, heavy metals can enter the food chain and pose significant risks to both aquatic life and human health [1]. Environmental pollution is closely associated with the ecological system. Any imbalance in the interactions among environmental components can disrupt ecosystem stability. Environmental pollution occurs when contaminants are introduced into the natural environment, causing adverse effects on living organisms and ecological processes [2]. Water pollution is defined as any physical or chemical change in water quality that negatively affects aquatic life or makes water unsuitable for its intended uses. Among the most dangerous pollutants in aquatic environments are heavy metals [3].

Heavy metals are elements with relatively high atomic weight and density greater than that of water. Examples include lead (Pb), zinc (Zn), arsenic (As), cadmium (Cd), copper (Cu), titanium (Ti), and mercury (Hg). These metals can exist either as metallic elements or dissolved salts in water. Approximately 31 elements are classified as metals in nature, of which 23 are considered heavy metals [4]. Heavy metal contamination has severe impacts on aquatic ecosystems. It results from human activities such as industrial discharges, agricultural runoff, sewage disposal, and pesticide use. Fish are particularly important indicators of aquatic pollution because they accumulate heavy metals through the food chain and from direct absorption through their gills [5]. The heavy metals enter aquatic food chains either directly through food consumption or indirectly through the gills. Through biomagnification, these metals can eventually reach humans, who occupy the top of the food chain. Therefore, fish are commonly used as biological indicators for monitoring environmental contamination by heavy metals [6]. Several factors influence heavy metal accumulation in fish, including habitat conditions, growth rate, feeding behavior, species type, and environmental metal concentrations [7].

The Libyan coastline is characterized by relatively straight shorelines with limited natural harbors. Among the important ports in eastern Libya is Sousa Harbor, located approximately 65 km from Derna and 30 km from Al-Bayda city [8]. Sousa Harbor is an important fishing port in the eastern region of Libya. The harbor is moderately sized and partially protected by artificial and natural rock barriers. The surrounding area consists mainly of rocky coastal terrain descending from the Green Mountain plateau [9]. Fish are widely recognized as reliable bioindicators of environmental pollution because of their ability to accumulate heavy metals from water, sediments, and food sources. The process of bioaccumulation leads to the gradual buildup of metals in different fish tissues, depending on factors such as species, size, feeding habits, and environmental conditions [10].

Aquatic ecosystems are increasingly threatened by heavy metal pollution resulting from anthropogenic activities such as industrial discharge, agricultural runoff, sewage effluents, and maritime operations [11]. Fish are widely regarded as effective bioindicators of aquatic pollution because they occupy different trophic levels and have the capacity to accumulate contaminants from water, sediments, and diet. The extent of heavy metal accumulation in fish depends on several factors, including species, age, size, metabolic activity, and environmental conditions. Importantly, the distribution of metals within fish is not uniform; metabolically active organs such as gills and liver tend to accumulate higher concentrations compared to muscle tissue, which generally exhibits lower levels but remains critical due to its

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direct relevance to human consumption [12]. Among fish organs, the distribution of heavy metals is not uniform; studies consistently show that muscles tend to have the lowest concentrations, while metabolically active and environmentally exposed organs such as gills and liver exhibit higher levels [13]. Gills play a vital role in respiration and osmoregulation and are continuously exposed to the surrounding aquatic environment, making them highly susceptible to heavy metal accumulation. Their large surface area and thin epithelial structure facilitate the rapid uptake of dissolved metals, especially toxic elements such as cadmium and lead. Consequently, gills are often used as sensitive indicators of waterborne pollution [13]. In contrast, muscle tissue reflects long-term accumulation patterns and is essential for assessing food safety and potential health risks to consumers [14]. Among fish species, grey mullet (*Mugil spp.*) is of particular importance due to its wide distribution in coastal and estuarine environments, as well as its economic and nutritional value in Mediterranean and North African regions. Its feeding habits, which include detritus and benthic organisms, increase its exposure to contaminants, making it a suitable model for environmental monitoring studies. Previous research has demonstrated that mullet species can accumulate significant levels of heavy metals, reflecting the degree of environmental pollution in their habitats [1,15]. Heavy metals, including copper (Cu), cadmium (Cd), and lead (Pb), are of particular concern due to their persistence, non-biodegradable nature, and potential for bioaccumulation in aquatic organisms. Once introduced into aquatic environments, these metals can remain for extended periods, undergoing bioaccumulation and biomagnification through the food chain, thereby posing serious ecological and human health risks [13]. Copper is an essential trace element required for enzymatic activities and physiological functions; however, excessive concentrations may lead to oxidative stress and cellular damage. In contrast, cadmium and lead are non-essential and highly toxic metals, even at low concentrations.

Cadmium exposure is associated with renal dysfunction and skeletal damage, while lead is known to cause neurological, hematological, and developmental disorders [16]. Therefore, monitoring these metals in fish tissues is crucial for evaluating environmental quality and ensuring public health safety. Copper is a chemical element with atomic number 29 and atomic weight 63.54. It occurs naturally either in elemental form or combined in oxide compounds. Copper is widely used in industrial applications due to its malleability and electrical conductivity. Although copper is essential for human health in small amounts, excessive exposure may lead to High blood pressure, Anemia, Nervous system disorders, Behavioral disturbances in children, Eye and nasal irritation, Headaches and vomiting, Liver and kidney damage. Copper is considered an essential trace element required for various physiological functions; however, excessive concentrations can lead to toxic effects. In contrast, cadmium and lead are non-essential and highly toxic metals, even at low concentrations, and are associated with severe biological and health impacts, including organ damage and neurological disorders. Therefore, monitoring their levels in fish tissues is critical for evaluating environmental quality and ensuring food safety [17].

Lead is a heavy metal with atomic number 82 and atomic mass 207.2. It has a bluish-silver color that quickly tarnishes to dull gray when exposed to air. Lead toxicity can cause hearing disorders, behavioral and learning problems, developmental abnormalities, nervous system damage, paralysis in severe cases, and accumulation in bones as lead phosphate [18]. Cadmium is a bluish-silver metal with atomic number 48 and atomic mass 112.41. It is commonly used in metal coatings and industrial applications. Exposure to cadmium may lead to lung inflammation when inhaled, increased risk of cancer, enzyme inhibition in biological systems, bone fragility (osteoporosis), and severe toxic effects at high exposure levels [19]. Sousa Harbor in Libya represents an important coastal area that may be subjected to various sources of pollution, including shipping activities and urban discharge. Despite its significance, limited data are available regarding heavy metal contamination in fish from this region. Therefore, assessing the levels of copper, cadmium, and lead in different tissues of mullet fish is essential for understanding contamination patterns and evaluating associated ecological and health risks [8,9]. Accordingly, the present study aims to assess the concentrations of copper, cadmium, and lead in the tissues and gills of mullet fish (*Mugil spp.*) collected from Sousa Harbor, Libya. This study provides valuable insights into the bioaccumulation behavior of heavy metals in different fish organs and contributes to the broader understanding of environmental pollution and food safety in the region.

Materials and Methods

Study Area

Sousa Harbor is located on the eastern Libyan coast, approximately 65 km from Derna and 30 km from Al-Bayda city. The harbor is considered one of the most important fishing ports in eastern Libya. The surrounding coastal area is characterized by rocky shorelines descending from the Green Mountain plateau. Fishing activities represent a primary economic activity in this region, making environmental monitoring of marine resources particularly important.

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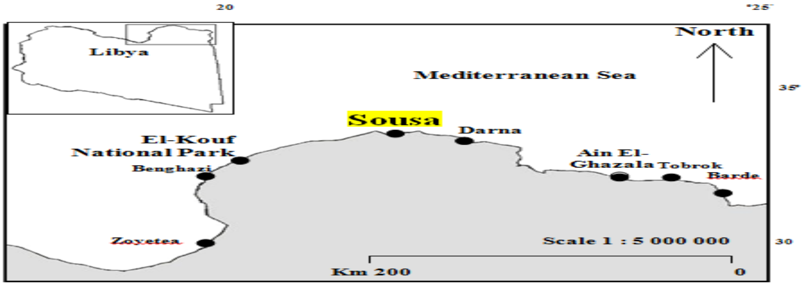

Figure 1. Map of the study area

Fish Samples

Mullet fish (Mugil spp.) were selected for this study. These fish typically inhabit warm coastal waters and feed on plankton, algae, and small invertebrates. Their average length ranges from 30–40 cm and may reach 60 cm.

Sample Preparation

Fresh fish samples were collected from Sousa Harbor. Fish were thoroughly washed with distilled water and dissected into two parts:

- Muscle tissue
- Gills

Each part was weighed separately. Samples were air-dried and then placed in a drying oven at 40°C for three days until completely dry. After drying, samples were ground into fine powder and prepared for wet digestion.

Wet Digestion Procedure

1. 0.5 g of each dried sample was weighed.
2. 5 mL nitric acid (HNO_3) and 5 mL sulfuric acid (H_2SO_4) were added.
3. The mixture was heated at 60°C until nearly dry.
4. Hydrogen peroxide (H_2O_2) was gradually added until the total volume reached 10 mL.
5. The final solution was diluted to 50 mL with distilled water.
6. Filtrates were stored in 100 mL volumetric flasks.

Heavy Metal Analysis

The concentrations of Cu, Cd, and Pb were determined using a Thermo Electron Corporation analytical instrument in the laboratory.

Statistical analysis

The data was statistically analyzed using a t-test to study the significant differences in the level of Copper, lead, and cadmium among the tissues and gills of the mullet fish. SPSSPC+ version 24 was used for performing the statistical analysis. The significance level was high when ($P < 0.01$), significant when ($P < 0.05$), and non-significant when ($P > 0.05$).

Results

Fish Measurements Before Drying

The biometric characteristics of fish prior to drying, as presented in (Table 1), provide a reliable baseline for evaluating subsequent processing effects. The total length ranged from 22 to 24 cm, with a mean of 23.08 ± 0.74 cm, while the total weight ranged from 93 –132 g with a mean 111.25 ± 15.44 g). Empty weight ranged from 83 – 117 g with a mean of 99.56 ± 13.85 g, compared to total weight, that reflects the proportion of viscera, which appears relatively low. While the tissue weight ranged from 48 to 70 g with a mean of 57.09 ± 8.56 g. also, Gill weight ranged from 3 to 5 with a mean of 3.74 ± 0.89 g, showed minimal variation across samples, which is expected given its relatively small contribution to total biomass.

Table (1). Fish measurements before drying.

Total length (Cm)	N	Minimum	Maximum	Mean Std. Deviation
	6	22	24	23.08±.74
Total weight (g)	6	93	132	111.25±15.44
Empty Weight (g)	6	83	117	99.56±13.85
Tissue Weight (g)	6	48	70	57.09±8.56
Gill Weight (g)	6	3	5	3.74±.89

Dry Weight of Samples Results

The dry weight results presented in (Table 2) provide important insights into moisture loss and tissue composition following the drying process. The tissue dry weight and gill dry weight showed a significant ($P< 0.01$) difference where the

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tissue dry weight ranged from 12.27 to 18.64 g, with a mean value of 14.97 ± 2.54 g. In contrast, gill dry weight showed a much lower range (0.59–1.15 g) with a mean of 0.78 ± 0.20 g.

Table (2). Dry weight sample results

	N	Minimum	Maximum	Mean±. Std. Deviation	t-test
Tissue dry weight	6	12.27	18.64	14.97±2.54	10.15**
Gill Dry weight	6	.59	1.15	.78±.20	

*** = Significant at (P < 0.01).*

Heavy metal

Lead

The results presented in (Table 3) demonstrate the distribution of lead (Pb) concentrations in fish tissue and gill samples, revealing marked differences between the two biological compartments. Lead levels in fish tissue ranged from 0.001 to 0.091 mg/kg, with a mean value of 0.02 ± 0.04 mg/kg. In contrast, significantly higher lead concentrations were observed in fish gills, ranging from 0.003 to 0.619 mg/kg, with a mean of 0.37 ± 0.25 mg/kg.

Table (3). Level of lead in the fish tissue and gill samples.

Group	N	Minimum	Maximum	Mean Std. Deviation	t-test
Fish tissue	6	0.001	0.091	.02±.04	2.96**
Fish gills	6	0.003	0.619	.37±.25	

*** = Significant at (P < 0.01)*

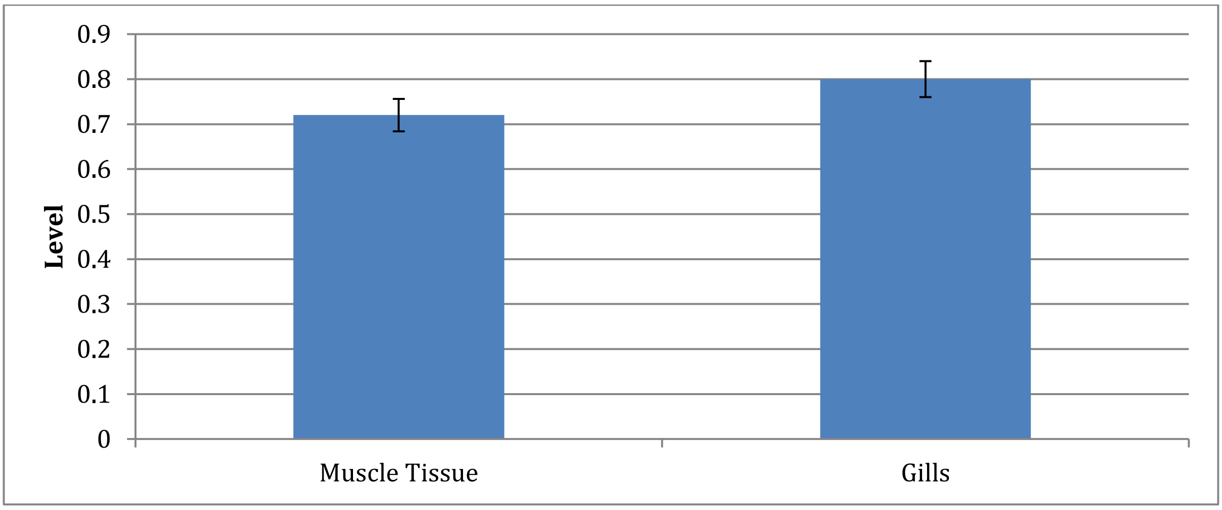

Figure (2). Level of lead among the fish tissue and gill samples.

Cadmium

The cadmium (Cd) concentrations presented in (Table 4) show measurable levels in both fish tissue and gill samples, with some variation between the two compartments. In fish tissue, cadmium levels ranged from 0.411 to 1.534 mg/kg, with a mean value of 0.84 ± 0.43 mg/kg. Fish gills exhibited slightly higher cadmium concentrations, ranging from 0.324 to 1.612 mg/kg, with a mean of 1.12 ± 0.49 mg/kg.

Table (4). Level of cadmium in fish tissue and gill samples.

Group	N	Minimum	Maximum	Mean±. Std. Deviation	t-test
Fish tissue	6	0.411	1.534	.84±.43	1.07NS
Fish gills	6	0.324	1.612	1.12±.49	

NS = Non-significant at (P > 0.05).

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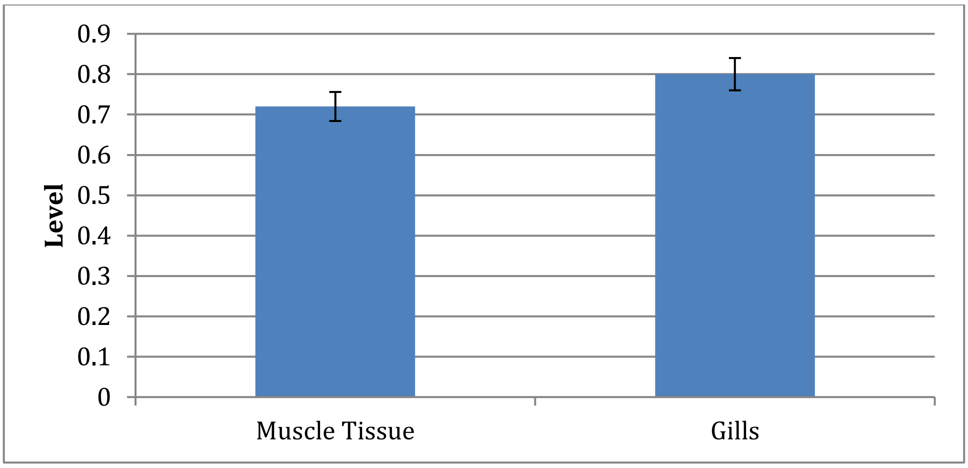

Figure (3). Level of cadmium in the fish tissue and gill samples

Copper

The copper (Cu) concentrations presented in (Table 5) demonstrate detectable levels in both fish tissue and gill samples, with relatively close mean values between the two groups. In fish tissue, copper levels ranged from 0.467 to 0.855 mg/kg, with a mean of 0.72 ± 0.19 mg/kg. In fish gills, copper concentrations ranged from 0.348 to 0.929 mg/kg, with a slightly higher mean of 0.80 ± 0.23 mg/kg.

Table (5). Level of copper in the fish tissue and gill samples

group	N	Minimum	Maximum	Mean± Std. Deviation	t-test
Fish tissue	6	0.467	0.855	0.72±.0.19	0.66NS
Fish gills	6	0.348	0.929	0.80±0.23	

NS = Non-significant at (P > 0.05)

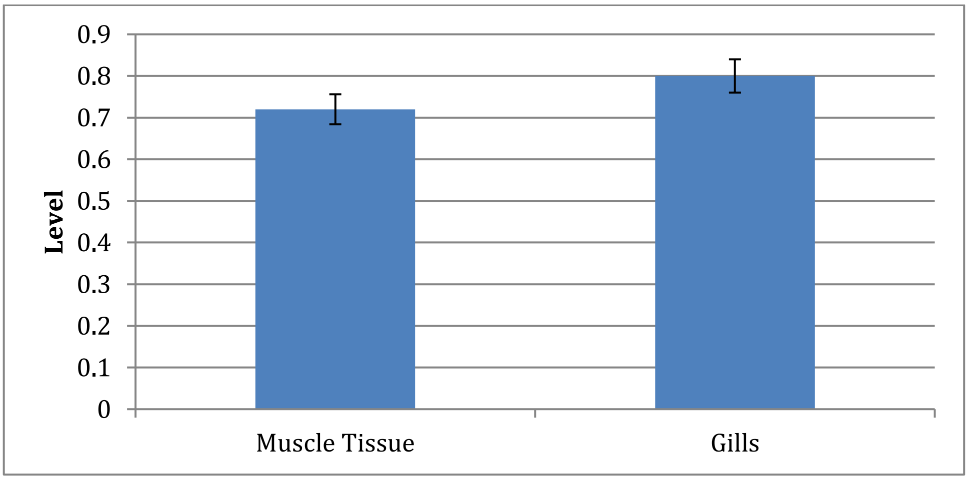

Figure (4). Level of copper in the fish tissue and gill samples

Discussion

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Our results on the fish Measurements Before Drying cleared that the biometric characteristics of fish prior to drying, as presented in (Table 1), provide a reliable baseline for evaluating subsequent processing effects. The total length ranged from 22 to 24 cm, with a mean of 23.08 ± 0.74 cm, indicating a high degree of homogeneity among the sampled fish. Such uniformity is essential in experimental studies, as it reduces size-related variability and improves the accuracy of comparisons, particularly in processing techniques like drying. The total weight (93–132 g; 111.25 ± 15.44 g) exhibited moderate variation, which may be attributed to natural biological differences such as feeding condition, metabolic status, and growth stage. Morphometric relationships between length and weight are well-documented in fish biology and are influenced by environmental and nutritional factors [15]. The observed variation is within normal biological limits for freshwater fish species. Empty weight (99.56 ± 13.85 g), compared to total weight, reflects the proportion of viscera, which appears relatively low. This observation is important in drying studies, as the removal of internal organs significantly affects moisture loss, drying rate, and product quality [20].

Fish with lower visceral mass typically exhibit more uniform drying behavior. The tissue weight (57.09 ± 8.56 g), representing the edible portion, is a key indicator of processing yield. Its proportion relative to total body weight reflects both flesh quality and economic value. Previous studies have demonstrated that muscle yield varies depending on species, size, and pre-processing handling conditions [1]. Gill weight (3.74 ± 0.89 g) showed minimal variation across samples, which is expected given its relatively small contribution to total biomass. Despite this, gills are of particular importance in environmental and toxicological studies, as they are highly sensitive to waterborne contaminants, including heavy metals, due to their direct exposure to the aquatic environment [13]. Overall, the results indicate that the fish samples are relatively uniform in their morphometric characteristics, providing a solid foundation for drying experiments and further chemical or microbiological analyses. Moreover, these findings are consistent with previously reported data in the literature, supporting the reliability and validity of the current measurements.

Our results on the dry Weight of samples showed that the dry weight results provide important insights into moisture loss and tissue composition following the drying process. The tissue dry weight ranged from 12.27 to 18.64 g, with a mean value of 14.97 ± 2.54 g. This variation reflects differences in initial moisture content, muscle composition, and structural characteristics of the fish tissue. Muscle tissues typically retain higher amounts of water compared to other body components, which explains the relatively higher dry weight values after dehydration. Such findings are consistent with previous studies indicating that fish muscle composition—particularly protein and lipid content—plays a key role in determining water-holding capacity and drying efficiency [1]. In contrast, gill dry weight showed a much lower range (0.59–1.15 g) with a mean of 0.78 ± 0.20 g. This is expected due to the delicate structure and lower mass of gill tissues compared to muscle. Gills are composed primarily of thin epithelial layers and vascular structures, which lose moisture rapidly during drying. The relatively low standard deviation suggests a consistent response to the drying process across samples, indicating uniform dehydration behavior in this tissue type. The statistical analysis revealed a highly significant difference ($t = 10.15$, $P < 0.01$) in tissue dry weight. This high level of significance indicates that the observed values are not due to random variation but reflect a true effect, likely related to the drying process and inherent biological differences among samples. Significant differences in dry weight are often associated with variations in initial composition, particularly protein and lipid levels, which influence water retention and dehydration kinetics [20]. From a processing perspective, these results highlight that muscle tissue retains a substantial proportion of its mass after drying compared to gills, making it the primary contributor to final product yield. Moreover, understanding dry weight distribution is essential for optimizing drying conditions, improving product quality, and ensuring consistency in industrial fish processing. Overall, the findings demonstrate clear differences between tissue types in terms of drying behavior and confirm that muscle tissue exhibits greater variability and higher residual mass than gills. These observations are in agreement with established literature on fish drying and tissue composition, supporting the reliability of the present results. Our results on the Level of lead among the fish tissue and gill samples demonstrate the distribution of lead (Pb) concentrations in fish tissue and gill samples, revealing marked differences between the two biological compartments.

Lead levels in fish tissue ranged from 0.001 to 0.091 mg/kg, with a mean value of 0.02 ± 0.04 mg/kg, indicating relatively low accumulation within the edible muscle portion. This observation is consistent with previous findings that muscle tissue generally exhibits lower heavy metal concentrations due to its lower metabolic activity and reduced direct exposure to the aquatic environment [10]. In contrast, significantly higher lead concentrations were observed in fish gills, ranging from 0.003 to 0.619 mg/kg, with a mean of 0.37 ± 0.25 mg/kg. The elevated levels in gills can be attributed to their physiological role as the primary site of respiration and direct interface with the surrounding water. Gills are highly vascularized and possess a large surface area, making them particularly susceptible to the adsorption and accumulation of dissolved heavy metals [13]. The statistical analysis revealed a significant difference between tissue and gill lead concentrations ($t = 2.96$, $P < 0.01$), indicating that the variation is not due to random chance but reflects a true biological and environmental effect. This significant disparity supports the concept of differential bioaccumulation, where certain organs (such as gills and liver) act as primary sites for contaminant uptake, while muscle tissue remains comparatively less affected [12].

From a public health perspective, the relatively low levels of lead detected in fish tissue suggest that the edible portion may fall within acceptable safety limits in many cases. However, the elevated concentrations in gills raise concerns regarding environmental pollution and the overall health status of the aquatic ecosystem. Chronic exposure to lead, even at low concentrations, is known to cause toxic effects in both aquatic organisms and humans, including neurological,

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hematological, and renal impairments [16]. Overall, these findings highlight the importance of monitoring heavy metal contamination in different fish organs, as reliance on muscle tissue alone may underestimate the extent of environmental pollution. The results are in agreement with contemporary studies that emphasize the role of gills as sensitive bioindicators of waterborne heavy metal contamination, thereby reinforcing their value in environmental assessment and risk evaluation. While our results on the level of cadmium among the fish tissue and gill samples indicated that the cadmium (Cd) concentrations presented in (Table 4) show measurable levels in both fish tissue and gill samples, with some variation between the two compartments. In fish tissue, cadmium levels ranged from 0.411 to 1.534 mg/kg, with a mean value of 0.84 ± 0.43 mg/kg. These values indicate a moderate accumulation of cadmium in the edible portion of the fish, which may be attributed to chronic environmental exposure, as cadmium is known to accumulate in aquatic organisms over time due to its non-biodegradable nature [12].

Fish gills exhibited slightly higher cadmium concentrations, ranging from 0.324 to 1.612 mg/kg, with a mean of 1.12 ± 0.49 mg/kg. This pattern aligns with the biological role of gills as a primary site for ion exchange and direct interaction with the aquatic environment, making them more susceptible to the uptake of dissolved heavy metals. However, unlike lead, the difference between tissue and gill cadmium levels was not statistically significant ($t = 1.07$, $P > 0.05$), indicating that cadmium distribution between these two tissues is relatively comparable. The lack of statistical significance suggests that cadmium may have a more uniform distribution within the fish body compared to other heavy metals. This can be explained by its ability to bind strongly to proteins such as metallothioneins, which facilitate its transport and accumulation across multiple tissues, including muscle [13]. As a result, cadmium does not remain localized in highly exposed organs like gills but can also be found in appreciable concentrations in edible tissues. From a toxicological standpoint, the detected cadmium levels raise potential concerns, as cadmium is a highly toxic metal associated with kidney damage, bone demineralization, and carcinogenic effects in humans upon long-term exposure [16]. The presence of comparable concentrations in both tissue and gills emphasizes the importance of comprehensive monitoring, especially since muscle tissue represents the primary route of human exposure. Overall, these findings indicate that cadmium contamination is present at notable levels in the studied fish samples, with a relatively even distribution between gills and muscle tissue. This contrasts with the pattern observed for lead and highlights the distinct bioaccumulation behavior of different heavy metals.

The results are consistent with previous studies that report widespread cadmium distribution in fish tissues due to its biochemical affinity and mobility within the organism. The results about the level of copper among the fish tissue and gill samples showed that the copper (Cu) concentrations presented in (Table 5) demonstrate detectable levels in both fish tissue and gill samples, with relatively close mean values between the two groups. In fish tissue, copper levels ranged from 0.467 to 0.855 mg/kg, with a mean of 0.72 ± 0.19 mg/kg. These values fall within the typical physiological range reported for fish muscle, as copper is an essential trace element involved in vital biological processes such as enzyme activity, oxidative metabolism, and hemoglobin synthesis [21]. In fish gills, copper concentrations ranged from 0.348 to 0.929 mg/kg, with a slightly higher mean of 0.80 ± 0.23 mg/kg. The marginally elevated levels in gills can be attributed to their direct contact with the aquatic environment, which facilitates the uptake of dissolved metals. Gills are known to act as an initial site for metal absorption before redistribution to internal tissues [12]. However, the difference between gill and tissue copper levels was not statistically significant ($t = 0.66$, $P > 0.05$), indicating a relatively uniform distribution of copper between these tissues. The absence of a significant difference suggests that copper, unlike non-essential toxic metals such as lead, is tightly regulated within the fish body through homeostatic mechanisms. Fish possess efficient physiological systems to maintain copper balance, including controlled absorption, storage, and excretion. Proteins such as metallothioneins play a crucial role in binding copper and preventing toxic accumulation, thereby ensuring that concentrations remain within safe biological limits [13].

From a nutritional and toxicological perspective, the detected copper levels are important but not necessarily alarming. Copper is required in small amounts for normal biological function in both fish and humans; however, excessive accumulation can lead to oxidative stress and tissue damage. The relatively moderate and comparable levels observed in both tissue and gills suggest that the studied fish are not exposed to excessive copper pollution [22]. Overall, these findings indicate that copper is present at physiologically relevant levels and is evenly distributed between fish tissue and gills, with no significant variation between the two. This pattern reflects the essential nature of copper and its regulated metabolism in fish, distinguishing it from other heavy metals such as lead and cadmium. The results are consistent with previous studies that highlight the controlled bioaccumulation of essential trace elements in aquatic organisms [23]. This study evaluated the concentrations of three heavy metals (Cu, Cd, and Pb) in mullet fish collected from Sousa Harbor, Libya.

Conclusion

The results concluded that the gills showed higher accumulation of heavy metals compared with muscle tissues. This finding indicates that fish gills act as a primary site for heavy metal uptake from the aquatic environment. The results highlight the importance of continuous monitoring of heavy metal contamination in marine environments to ensure the safety of aquatic ecosystems and seafood consumption. So we recommended that regular monitoring of heavy metals in marine environments should be conducted to assess pollution levels. Industrial and domestic waste discharge into marine waters should be strictly regulated. Public awareness programs should be implemented to educate communities

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about the risks of marine pollution. Proper fish handling, cleaning, and cooking practices should also be encouraged to reduce potential health risks.

Conflict of interest. Nil

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