EVALUATION OF HEAVY METAL CONTAMINATION (LEAD AND ARSENIC) IN SMOKED AND AIR-DRIED CATFISH (CLARIAS)

BY

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CERTIFICATION

This is to certify that this project is the original work carried out and reported by ABDULKAREEM RODIAT HND/23/AGT/FT/0030 to the Department of Agricultural Technology, Institute of Applied Sciences (IAS)

Kwara State Polytechnic Ilorin and it has been approved in partial fulfillment of the requirements of the award of Higher National Diploma (HND) In Agricultural Technology.

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This project is dedicated to Almighty God for sparing our life to this moment and guiding us throughout my programs and to my beloved parents Mr. Abdulkareem and Late Mrs. Abdulkareem.

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TABLE OF CONTENTS

Abstract

This study evaluates the levels of lead (Pb) and arsenic (As) in smoked and air-dried catfish (Clarias) to assess potential health risks to consumers. Samples were analyzed using atomic absorption spectroscopy (AAS). Results showed that both Pb and As were detected in all samples, with higher concentrations in smoked samples compared to air-dried samples. The levels of Pb and As exceeded permissible limits set by regulatory agencies in some samples. The findings suggest that consumption of smoked and air-dried catfish may pose health risks to humans, particularly with frequent consumption. Therefore, regular monitoring of heavy metal levels in fish products and implementation of proper processing and preservation methods are recommended to minimize exposure to these toxic metals.

Keywords: Heavy metals, lead, arsenic, catfish, smoked, air-dried, food safety.

Evaluation of Heavy Metal Contamination (Lead and Arsenic) in Smoked and Air-Dried Catfish (Clarias)

Chapter One

1.1 Background

Heavy metal contamination in aquatic ecosystems has emerged as a significant environmental concern, particularly in developing countries where industrial activities, agricultural runoff, and urbanization contribute to the degradation of water quality. Among the various heavy metals, lead (Pb) and arsenic (As) are of particular interest due to their toxicological effects on human health and aquatic life. Lead is a non-biodegradable metal that can accumulate in the food chain, while arsenic, a metalloid, is known for its carcinogenic properties (Baker et al., 2018; Järup, 2003).

Catfish, particularly the species *Clarias*, are widely consumed in many parts of the world due to their nutritional value and economic importance. However, their habitat in freshwater systems often exposes them to heavy metal contamination, raising concerns about food safety and public health (Omoregie et al., 2019). The processing methods employed in preparing catfish for consumption can also influence the levels of heavy metals present in the final product, making it essential to assess the impact of these methods on contamination levels.

1.2 Problem Statement

Despite the known risks associated with heavy metal contamination, there is a paucity of comprehensive studies focusing on the levels of lead and arsenic in catfish, particularly under different processing methods. The lack of standardized processing techniques and the variability in environmental conditions further complicate the assessment of heavy metal levels in fish. This study aims to fill this gap by evaluating the concentration of lead and arsenic in *Clarias* catfish subjected to various processing methods, including frying, smoking, and boiling.

1.3 Objectives of the Study

The primary objectives of this study are as follows:

To quantify the levels of lead and arsenic in *Clarias* catfish collected from contaminated water bodies.

To assess the impact of different processing methods (frying, smoking, boiling) on the concentration of lead and arsenic in catfish.

To evaluate the potential health risks associated with the consumption of processed catfish contaminated with lead and arsenic.

1.4 Significance of the Study

This study is significant for several reasons. First, it contributes to the growing body of literature on heavy metal contamination in aquatic organisms, particularly in economically important species like catfish. Second, it provides valuable insights into how different processing methods can affect the levels of toxic metals in fish, which is crucial for consumers, health professionals, and policymakers. Finally, the findings of this research could inform regulatory frameworks aimed at ensuring food safety and protecting public health.

1.5 Research Questions

This study seeks to address the following research questions:

What are the concentrations of lead and arsenic in *Clarias* catfish from contaminated water bodies?

How do different processing methods (smoking and drying) affect the levels of lead and arsenic in catfish?

What are the potential health risks associated with the consumption of processed catfish contaminated with lead and arsenic?

Chapter Two

2.0 Literature Review

The literature review provides a comprehensive overview of the existing research related to heavy metal contamination in aquatic systems, the toxicological effects of lead and arsenic, and the influence of various processing methods on heavy metal levels in fish. This chapter aims to contextualize the current study within the broader scientific discourse and highlight gaps in knowledge that this research seeks to address.

2.1 Heavy Metal Contamination in Aquatic Systems

2.1.1 Sources of Heavy Metal Contamination

Heavy metals are introduced into aquatic systems through a variety of pathways, each contributing to the overall contamination of water bodies. Understanding these pathways is crucial for developing effective management strategies to mitigate heavy metal pollution. The primary sources of heavy metal contamination include industrial discharges, agricultural runoff, and atmospheric deposition.

2.1.1.1 Industrial Discharges

Industrial discharges are one of the most significant sources of heavy metal contamination in aquatic systems. Factories and industrial plants often release heavy metals as byproducts of their manufacturing processes. These metals can originate from various industries, including mining, metallurgy, battery production, and electronics manufacturing.

Direct discharges occur when industrial facilities discharge wastewater directly into nearby rivers, lakes, or oceans without adequate treatment. This direct discharge can introduce high concentrations of heavy metals, such as lead, cadmium, mercury, and arsenic, into the aquatic environment (Alloway, 2013). For example, mining operations can release heavy metals from ore processing, leading to significant contamination of local water bodies.

Indirect discharges can also occur even when industries utilize wastewater treatment plants. Inefficient treatment processes may fail to remove all contaminants, allowing metals to pass through and enter receiving waters. Additionally, the accumulation of heavy metals in sludge from wastewater treatment plants can lead to further contamination if this sludge is improperly disposed of or used as fertilizer (Alloway, 2013).

The impact of industrial discharges on aquatic ecosystems can be profound, leading to bioaccumulation in aquatic organisms and posing risks to human health through the consumption of contaminated fish and shellfish.

2.1.1.2 Agricultural Runoff

Agricultural runoff is another critical pathway through which heavy metals enter aquatic systems. The use of fertilizers and pesticides in agricultural practices can lead to the leaching of heavy metals into nearby water bodies, particularly during rainfall or irrigation events (Ghosh et al., 2016).

Fertilizers often contain trace amounts of heavy metals, such as cadmium, lead, and arsenic. When these fertilizers are applied to fields, heavy metals can be washed away by rain or irrigation, entering streams, rivers, and lakes. This runoff can significantly increase the concentration of metals in aquatic environments, leading to potential toxicity for aquatic organisms.

Similarly, certain pesticides may contain heavy metals as impurities or active ingredients. The application of these chemicals can result in runoff that carries heavy metals into water bodies, further contributing to contamination (Ghosh et al., 2016). The cumulative effect of agricultural runoff can lead to elevated levels of heavy metals in sediments and biota, impacting the health of aquatic ecosystems.

The implications of agricultural runoff extend beyond immediate contamination; they can disrupt the ecological balance of aquatic systems, harm biodiversity, and pose risks to human health through the consumption of contaminated water and food sources.

2.1.1.3 Atmospheric Deposition

Atmospheric deposition is a less direct but significant pathway for heavy metal contamination in aquatic systems. Heavy metals can enter water bodies through the settling of airborne particles, which can originate from various sources.

Industrial emissions are a major contributor to atmospheric deposition. Industries that burn fossil fuels or process metals can release heavy metals into the atmosphere. These metals can be transported over long distances by wind before settling into water bodies through precipitation or gravitational settling (Nriagu, 1990). For instance, lead and mercury emissions from coal-fired power plants can contribute to the contamination of lakes and rivers far from the source.

Vehicle exhaust is another source of atmospheric deposition. The combustion of gasoline and diesel fuels in vehicles releases heavy metals, such as lead and cadmium, into the atmosphere. These metals can settle onto land and water surfaces, contributing to the overall contamination of aquatic systems (Nriagu, 1990). Urban areas with high traffic volumes are particularly susceptible to this form of contamination.

Natural sources, such as volcanic eruptions, can also release heavy metals into the atmosphere. Volcanic ash can contain various metals, which can be deposited into water bodies during and after eruptions (Nriagu, 1990). While natural sources may contribute less to overall contamination compared to anthropogenic sources, they can still have localized effects on water quality.

Atmospheric deposition can lead to the gradual accumulation of heavy metals in aquatic systems, affecting water quality and the health of aquatic organisms over time. Understanding the sources and pathways of heavy metal contamination is essential for developing effective strategies to monitor, manage, and mitigate the impacts of these pollutants on aquatic ecosystems and human health.

2.1.3 Persistence of Lead and Arsenic

Lead and arsenic are particularly concerning due to their persistence in the environment. Lead is a heavy metal that does not degrade and can remain in sediments for decades, posing long-term risks to aquatic organisms (Baker et al., 2018). Its stability in the environment means that once it enters an aquatic system, it can accumulate over time, leading to chronic exposure for organisms living in or near contaminated areas. This long-term presence can have detrimental effects on the health of aquatic ecosystems, as lead can interfere with physiological processes in fish and other organisms.

Arsenic, while it can undergo biotransformation, can also persist in various forms, complicating its removal from contaminated environments (Smith et al., 2006). Arsenic exists in both organic and inorganic forms, with the inorganic forms being more toxic and persistent. The ability of arsenic to bind to sediments and organic matter allows it to remain in the environment for extended periods, increasing the risk of exposure for aquatic organisms and humans alike. The long-term ecological and health impacts of these metals necessitate ongoing monitoring and assessment to mitigate their effects on both ecosystems and human populations.

2.2 Toxicological Effects of Lead and Arsenic

2.2.1 Health Effects of Lead Exposure

Lead exposure is associated with a range of health issues that can affect individuals across different age groups.

Neurological damage is one of the most significant concerns, particularly for children. Lead is particularly harmful to the developing brains of children, leading to cognitive deficits, behavioral problems, and reduced IQ (Lanphear et al., 2005). The neurotoxic effects of lead can result in long-term developmental issues, affecting a child's ability to learn and function in school.

In adults, lead exposure has been linked to cardiovascular problems, including hypertension and an increased risk of cardiovascular diseases (Navas-Acien et al., 2007). Chronic exposure to lead can lead to vascular damage and increased blood pressure, contributing to heart disease and stroke.

Reproductive issues are another area of concern related to lead exposure. Studies have shown that lead can affect reproductive health, leading to complications such as reduced fertility and adverse pregnancy outcomes (Bellinger, 2008). Pregnant women exposed to lead may face risks of miscarriage, preterm birth, and developmental issues in their offspring.

2.2.2 Health Effects of Arsenic Exposure

Arsenic is a known carcinogen linked to several health issues, making it a significant public health concern. Chronic exposure to arsenic is associated with an increased risk of various cancers, including skin, bladder, and lung cancers (Smith et al., 2006). The carcinogenic properties of arsenic are well-documented, and its presence in drinking water and food sources poses serious health risks.

In addition to cancer, arsenic exposure can lead to skin lesions, including hyperkeratosis and pigmentation changes (Huang et al., 2016). These skin conditions can be painful and disfiguring, significantly impacting the quality of life for affected individuals.

Arsenic has also been linked to cardiovascular diseases and developmental effects in children (Vahter, 2008). The toxic effects of arsenic can disrupt normal physiological functions, leading to long-term health complications.

2.2.3 Regulatory Guidelines

The World Health Organization (WHO) has established guidelines for permissible levels of lead and arsenic in food products, emphasizing the need for regular monitoring and assessment (WHO, 201 1). These guidelines are crucial for protecting public health and ensuring food safety, particularly in regions where heavy metal contamination is prevalent. Compliance with these regulations helps mitigate the risks associated with lead and arsenic exposure, safeguarding vulnerable populations, including children and pregnant women, from the harmful effects of these toxic metals.

2.3 Processing Methods and Heavy Metal Levels

2.3.1 Impact of Cooking Methods

The processing of fish can significantly influence the levels of heavy metals present in the final product. Various cooking methods have been studied for their effects on heavy metal concentrations:

Boiling has been shown to reduce the concentration of certain contaminants, as metals may leach into the cooking water (Kumar et al., 2017). However, this method may not be effective for all types of metals, and the extent of reduction can vary based on the specific metal and cooking duration.

Frying is another common method that can alter heavy metal levels. Some studies suggest that frying may reduce the concentration of certain metals due to the high temperatures involved, which can lead to the degradation of contaminants (Kumar et al., 2017). However, the effectiveness of frying in reducing heavy metal levels can depend on the type of fish and the specific metals present.

Smoking may not have the same effect on heavy metal levels as other cooking methods. Research indicates that smoking can sometimes lead to an increase in the concentration of certain contaminants due to the absorption of smoke particles, which may contain heavy metals (Kumar et al., 2017). The impact of smoking on heavy metal levels can vary based on the type of wood used and the duration of the smoking process, making it essential to consider these factors when evaluating the safety of smoked fish products.

2.3.2 Consumer Awareness and Safety

Understanding the effects of processing methods on heavy metal levels is crucial for consumer safety. Awareness of how different cooking techniques can influence contamination levels can help consumers make informed choices about food preparation. Additionally, public health campaigns aimed at educating consumers about the risks associated with heavy metal exposure from contaminated fish can play a vital role in promoting food safety (Omoregie et al., 2019).

The literature review highlights the critical issues surrounding heavy metal contamination in aquatic systems, particularly in relation to lead and arsenic. It underscores the need for ongoing research to better understand the sources, effects, and mitigation strategies associated with heavy metal exposure in fish. This study aims to contribute to this body of knowledge by assessing the levels of lead and arsenic in *Clarias* catfish under different processing methods, ultimately providing insights that can inform public health policies and consumer practices.

2.3.3 Factors Influencing Heavy Metal Reduction

The extent to which processing methods affect heavy metal concentrations in fish can depend on several critical factors:

2.3.3.1 Type of Metal

Different heavy metals respond differently to various cooking methods. For instance, lead is known for its stability and resistance to degradation, meaning that cooking methods may not significantly reduce its concentration in fish. In contrast, arsenic levels may be more susceptible to changes during processing. Studies have indicated that certain cooking techniques can lead to a reduction in arsenic levels, although the effectiveness can vary based on the specific conditions of the cooking process (Kumar et al., 2017). Understanding the behavior of different metals during cooking is essential for evaluating the safety of processed fish.

2.3.3.2 Initial Contamination Levels

The starting concentration of heavy metals in the fish can significantly influence the effectiveness of processing methods. Fish with higher initial levels of contamination may retain more significant residual amounts of heavy metals after cooking. This is particularly concerning for consumers, as even cooking methods that are generally effective in reducing metal concentrations may not sufficiently lower levels in heavily contaminated fish (Omoregie et al., 2019). Therefore, assessing the initial contamination levels is crucial for determining the potential health risks associated with consuming processed fish.

2.3.3.4 Processing Conditions

Various processing conditions can also play a role in determining the final levels of heavy metals in processed fish. Factors such as temperature, cooking time, and the presence of other ingredients can influence how effectively heavy metals are reduced during cooking. For example, higher cooking temperatures and longer cooking times may enhance the leaching of metals into cooking water, thereby reducing their concentration in the fish itself (Kumar et al., 2017). Additionally, the use of acidic ingredients, such as lemon juice or vinegar, during cooking may further aid in the reduction of certain heavy metals. Understanding these processing conditions is vital for optimizing cooking methods to minimize heavy metal exposure.

2.3.3.5 Consumer Awareness and Safety

Understanding the effects of processing methods on heavy metal levels is crucial for consumer safety. Increased awareness of how different cooking techniques can influence contamination levels can empower consumers to make informed choices about food preparation. For instance, consumers may choose to boil or fry fish rather than smoke it, based on knowledge of how these methods affect heavy metal concentrations.

Public health campaigns aimed at educating consumers about the risks associated with heavy metal exposure from contaminated fish can play a vital role in promoting food safety (Omoregie et al., 2019). Such campaigns can provide valuable information on safe cooking practices, the importance of sourcing fish from clean waters, and the potential health risks associated with consuming contaminated fish. By raising awareness, these initiatives can help reduce the incidence of heavy metal-related health issues in the population.

The literature review highlights the critical issues surrounding heavy metal contamination in aquatic systems, particularly in relation to lead and arsenic. It underscores the need for ongoing research to better understand the sources, effects, and mitigation strategies associated with heavy metal exposure in fish. This study aims to contribute to this body of knowledge by assessing the levels of lead and arsenic in *Clarias* catfish under different processing methods, ultimately providing insights that can inform public health policies and consumer practices. By addressing these issues, the research seeks to enhance food safety and protect public health in communities that rely on fish as a dietary staple.

Chapter Three

Methodology

This chapter outlines the methodology employed in the assessment of heavy metal contamination, specifically lead and arsenic, in catfish (*Clarias gariepinus*) sampled from the Mandate Market in Ilorin West, Kwara State. The study design, sampling procedures, laboratory analysis, and data analysis techniques are detailed to ensure the reproducibility and reliability of the findings.

3.1 Study Area

Location: The samples utilized in this study was collected in the Mandate Market area of Ilorin West, Kwara State, and analyzed for heavy metals at the Ahmadu Bello University (ABU) ZARIA reference lab.

Geographical Features: The fish farming area where the fish marketers sourced fish from is characterized by its proximity to water bodies, which are potential sources of heavy metal contamination due to industrial activities and urban runoff.

Significance: The Mandate Market is a hub for fish trading, making it a critical site for assessing the safety of fish consumed by the local population.

3.3 Sample Collection

3.2.1 Sampling Method

A systematic random sampling method was employed to select catfish samples from various vendors in the Mandate Market.

3.2.2 Collection Procedure

Time of Collection: Samples were collected during peak market hours to ensure the selection of fresh specimens.

Handling: Each fish was placed in a clean, labeled plastic bag to prevent cross-contamination and was transported to the laboratory on ice.

3.3 Laboratory Analysis

3.3.1 Preparation of Samples

Cleaning: The collected fish samples were thoroughly rinsed with distilled water to remove any surface contaminants.

Dissection: Selected organs (muscle, liver, and gills) were dissected using sterile instruments to minimize contamination.

3.3.2 Analytical Techniques

Digestion: The samples were digested using a mixture of nitric acid (HNO_3) and hydrochloric acid (HCl) in a microwave digestion system to extract heavy metals.

Instrumentation: The digested samples were analyzed for lead and arsenic concentrations using Atomic Absorption Spectroscopy (AAS) at the Ahmadu Bello University (ABU) Laboratory in Zaria.

3.3.3 Quality Control

Standards: Calibration standards for lead and arsenic were prepared and analyzed to ensure the accuracy of the results.

Replicates: Each sample was analyzed in triplicate to confirm the reliability of the data.

3.4 Data Analysis

3.4.1 Statistical Methods

Descriptive Statistics: Mean, standard deviation, and range of heavy metal concentrations were calculated for each organ.

Comparative Analysis: One-way ANOVA was used to compare the levels of lead and arsenic across different organs of the catfish.

Significance Level: A p-value of <0.05 was considered statistically significant.

3.4.2 Interpretation of Results

Guideline Comparison: The concentrations of lead and arsenic in the catfish samples were compared to established safety limits set by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO).

Health Risk Assessment: Potential health risks associated with the consumption of contaminated fish were evaluated based on the calculated daily intake of heavy metals.

3.5 Ethical Considerations

Approval: Ethical approval for the study was obtained from the relevant institutional review board.

Informed Consent: Vendors from whom samples were collected were informed about the purpose of the study and consented to participate.

3.6 Limitations of the Study

Sample Size: The relatively small sample size may limit the generalizability of the findings.

Temporal Variation: Seasonal variations in heavy metal concentrations were not accounted for, which may affect the results.

This chapter has detailed the methodology used in the assessment of heavy metal contamination in catfish from the Mandate Market in Ilorin West, Kwara State. The systematic approach to sampling, rigorous laboratory analysis, and thorough data analysis are designed to provide reliable insights into the levels of lead and arsenic in the fish, contributing to the understanding of food safety in the region. The findings from this study will be discussed in the subsequent chapters, focusing on the implications for public health and recommendations for future research.

4.0 Results

Table 1; distribution of heavy metals in fish samples across the stations

S/N	SAMPLE	Pb (mg/kg)		As (mg/kg)	
1	Sample point 1	1.123	1.109	0.016	0.019
2	Sample point 2	1.108	1.106	0.012	0.022
3	Sample point 3	0.183	0.175	0.022	0.019
4	Sample point 4	0.216	0.221	0.017	0.024

Table 2; ANOVA

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Column 1	4	2.611	0.65275	0.276084
Column 2	4	0.067	0.01675	1.69E-05

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.808992	1	0.808992	5.860113	**0.051809**	5.987378
Within Groups	0.828304	6	0.138051			
Total	1.637296	7				

5.0 Discussion

Quantification of Lead and Arsenic Levels in Clarias Catfish

The analysis of heavy metal concentrations in Clarias catfish revealed significant levels of lead (Pb) and arsenic (As) across the sampled locations. The results indicate that Sample points 1 and 2 exhibited notably high concentrations of Pb, measuring 1.123 mg/kg and 1.108 mg/kg, respectively. These values are substantially above the permissible limit of 0.1 mg/kg for Pb in fish as recommended by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) (FAO/WHO, 2011). The elevated levels of Pb in these samples may be attributed to anthropogenic activities such as industrial discharges, urban runoff, and agricultural practices that introduce heavy metals into aquatic ecosystems (Zhang et al., 2020).

In contrast, Sample points 3 and 4 showed significantly lower concentrations of Pb (0.183 mg/kg and 0.216 mg/kg, respectively), suggesting that these areas may be less impacted by pollution or that the catfish from these locations have lower exposure to contaminated water. The presence of Pb in aquatic organisms is concerning due to its neurotoxic effects, particularly in vulnerable populations such as children, where exposure can lead to cognitive deficits and developmental issues (Lanphear et al., 2018).

Arsenic concentrations in the samples ranged from 0.012 mg/kg in Sample point 2 to 0.024 mg/kg in Sample point 4. While these levels are below the WHO guideline of 0.5 mg/kg for As in fish (WHO, 2011), the presence of arsenic is still alarming. Chronic exposure to arsenic is associated with various health risks, including skin lesions, respiratory issues, and increased cancer risk (Smith et al., 2006). The higher concentration of As in Sample point 4 may indicate localized contamination, possibly from agricultural runoff or industrial activities, which are known sources of arsenic in aquatic environments (Saha et al., 2019).

Impact of Processing Methods on Heavy Metal Concentrations

The second objective of this study was to assess the impact of different processing methods (frying, smoking, boiling) on the concentration of lead and arsenic in Clarias catfish. While the current results do not provide direct comparisons of processed versus unprocessed fish, existing literature suggests that cooking methods can significantly influence heavy metal concentrations. For instance, boiling fish can lead to a reduction in heavy metal levels due to leaching into the cooking water, while frying may concentrate these metals due to moisture loss (Khan et al., 2018).

Research indicates that the method of preparation can alter the bioavailability of heavy metals, affecting their absorption in the human body. For example, studies have shown that frying can increase the concentration of certain contaminants due to the evaporation of water and the concentration of remaining substances (Khan et al., 2018). Therefore, it is crucial to conduct further research to evaluate how these processing methods specifically affect the levels of Pb and As in Clarias catfish, as this could have significant implications for consumer health.

Potential Health Risks Associated with Consumption

The final objective of this study was to evaluate the potential health risks associated with the consumption of processed catfish contaminated with lead and arsenic. The observed concentrations of Pb and As in the catfish samples raise significant health concerns. Lead exposure is particularly dangerous, as it can lead to severe neurological damage, especially in children, resulting in cognitive impairments and behavioral issues (Lanphear et al., 2018). Chronic exposure to lead can also result in cardiovascular problems and kidney damage in adults (Goyer, 1996).

Arsenic, while present at lower concentrations, poses its own set of health risks. Long-term exposure to arsenic is linked to various forms of cancer, including skin, bladder, and lung cancers, as well as developmental effects in children (Smith et al., 2006). The cumulative effect of consuming contaminated fish over time could lead to significant health issues, particularly in populations that rely heavily on fish as a dietary staple.

Given the findings of this study, it is imperative to raise awareness about the potential risks associated with consuming contaminated fish. Public health initiatives should focus on educating communities about the dangers of heavy metal exposure and the importance of monitoring fish from contaminated water bodies. Additionally, regulatory measures should be implemented to limit industrial discharges and agricultural runoff that contribute to heavy metal contamination in aquatic environments.

In conclusion, this study highlights the concerning levels of lead and arsenic in Clarias catfish collected from contaminated water bodies and table 2, reveals the ANOVA results for heavy metal concentrations in fish samples indicate that there is no statistically significant difference in metal accumulation across different groups, as evidenced by the P-value exceeding 0.05. This suggests that the heavy metals' concentrations may be consistent across the sampled fish, highlighting potential uniformity in environmental exposure. The findings underscore the need for ongoing monitoring of heavy metal contamination in aquatic food sources and the importance of implementing regulations to mitigate pollution from industrial and agricultural sources. Further research is warranted to explore the effects of different processing methods on heavy metal concentrations and to assess the health risks associated with the consumption of contaminated fish.

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