# DETERMINATION OF THE LEVEL OF HEAVY METALS AND POLYCYCLIC AROMATIC-HYDROCARBON (PAHS) IN ROADSIDE SUYA COMMERCIALLY AVAILABLE IN UGBOWO, BENIN CITY, EDO STATE: A COMPARATIVE STUDY.

**BY**

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## CERTIFICATION

This is to certify that this research project was carried out by MIEYESEGHA PEREKEME EMMANUEL with the matriculation number PSC2209430 under the supervision of Dr. J.N. JACOB in the Department of Chemistry, Faculty of Physical sciences, University of Benin, Benin City, Edo State.

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## DEDICATION

This project research is dedicated to the Almighty God who in His infinite mercy saw me through my journey in the University of Benin, to my loving Family.

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I am filled with immense joy as I express gratitude to everyone who played a part in making this endeavor a success. First and foremost, profound gratitude is directed towards the Almighty for His guidance and providence throughout this journey.

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# ABSTRACT

This study assessed the levels of selected heavy metals and polycyclic aromatic hydrocarbons (PAHs) in suya meat sold in Ugbowo, Benin City, to evaluate its safety for consumers. Ugbowo is a busy area with dense traffic and open-air vending that exposes food to contamination from vehicle emissions, dust, and smoke. Two composite suya samples were analyzed—one obtained from roadside vendors along major express routes and the other from residential areas including 19th Street, BDPA, and Edo Street in Ekosodin. The samples were oven-dried, homogenized, digested with nitric acid and hydrogen peroxide, and analyzed for heavy metals using Atomic Absorption Spectrophotometry (AAS). Polycyclic aromatic hydrocarbons (PAHs) were extracted and determined using Gas Chromatography–Mass Spectrometry (GC–MS). The AAS results showed the presence of lead (Pb), cadmium (Cd), copper (Cu), and nickel (Ni), while chromium (Cr) was below detection in both samples. Concentrations (mg/kg) for express road samples and residential sample were Pb (4.348, 5.002), Cr (<0.001, <0.001), Cu (1.635, 0.654), Cd (4.381, 3.988), and Ni (9.578, 5.230), all exceeding WHO/FAO permissible limits, indicating contamination likely from road dust, metal grills, or fuel combustion. GC–MS analysis revealed that all sixteen priority PAHs were below the detection limit (0.000 mg/kg) in both samples, suggesting minimal formation during grilling. Overall, the results indicate that while PAH contamination was negligible, heavy metal levels were significantly high, posing potential health risks to frequent consumers. The study recommends regular monitoring of street-vended foods and improved hygiene and roasting practices among suya vendors in Benin City.

# CHAPTER ONE

## 1.1 Introduction

Suya is a popular grilled meat commonly sold along roadsides and open markets across Nigeria, including Ugbowo in Benin City. It serves as an affordable protein source for many residents and students. However, its method of preparation and sale exposes it to possible contamination from vehicle emissions, dust, and metallic utensils (Laoye *et al.,* 2025). These factors can introduce heavy metals such as chromium (Cr), nickel (Ni), copper (Cu), lead (Pb), and cadmium (Cd), as well as polycyclic aromatic hydrocarbons (PAHs) into the meat, raising food safety concerns.

Heavy metals are elements that accumulate in animal tissues and remain in the food chain for long periods. Unlike organic contaminants, they do not degrade easily (Ogechi *et al.,* 2025). Consumption of food contaminated with high levels of lead or cadmium can affect the kidneys, liver, and nervous system, while PAHs and chromium are linked to cancer and skin disorders (Peydayesh *et al.,* 2022). Continuous intake of small amounts from everyday food, like suya, can gradually pose serious health risks, especially where environmental pollution is high.

Monitoring the levels of heavy metals and polycyclic aromatic hydrocarbons (PAHs) in roadside suya meat is important for public health protection. Ugbowo is a busy area with heavy traffic and commercial activities, exposing roadside foods to contamination from vehicle emissions and incomplete charcoal combustion. This study focuses on determining the concentrations of chromium, nickel, copper, lead, cadmium, and PAHs in suya meat sold in Ugbowo, Benin City. The results will be compared with WHO/FAO permissible limits to assess possible health risks to regular consumers.

## 1.2 Background of the Study

The contamination of food by heavy metals and polycyclic aromatic hydrocarbons (PAHs) has become a growing environmental and public health issue, especially in urban areas of developing countries. Rapid industrialization, traffic congestion, and poor waste management contribute significantly to the spread of toxic substances in air, soil, and water. These pollutants eventually find their way into the food chain through crops, livestock, and street-vended foods (Mititelu *et al.,* 2025). In Nigeria, roadside foods like suya are often prepared and sold in open environments exposed to vehicular emissions and dust, which are major sources of lead (Pb), cadmium (Cd), nickel (Ni), and other metals. In addition, incomplete combustion of charcoal during grilling releases PAHs—carcinogenic organic compounds that can deposit on the meat surface. Such exposure increases the likelihood of contaminant accumulation in meat consumed daily by the public (Ekhator *et al.,* 2017).

Heavy metals such as chromium (Cr), copper (Cu), lead (Pb), cadmium (Cd), and nickel (Ni), along with PAHs, are persistent environmental pollutants that bioaccumulate in biological tissues. While some metals like Cu and Ni are essential in trace amounts, excessive levels disrupt metabolic activities and can cause organ damage, reproductive issues, and cancer (Tchounwou *et al.,* 2014). PAHs, on the other hand, are known to induce genetic mutations and promote carcinogenesis when consumed in contaminated food. Previous studies have shown that roadside food items in urban centers often exceed safe limits due to proximity to traffic, use of contaminated ingredients, and handling with metal tools or grills (Oluwakemisola, 2025). This makes the assessment of heavy metals and PAHs in street foods a reliable indicator of environmental pollution and food safety standards.

Ugbowo, a major commercial area in Benin City, experiences dense vehicular movement and roadside trading. Suya sold here may absorb contaminants from exhaust fumes, airborne dust, and soot from burning charcoal. Despite its popularity, little data exist on the levels of heavy metals and PAHs in suya consumed in this locality. This study therefore investigates the concentrations of these contaminants in roadside suya meat sold in Ugbowo, providing scientific evidence for consumer safety assessment and environmental monitoring.

### 1.3 Statement of the Problem

Urban food vending has become a vital part of daily life in Nigerian cities, providing quick, affordable meals to millions. Among these, suya remains one of the most consumed street foods because of its taste, accessibility, and low cost (Mazi *et al.,* 2023). However, its open-air preparation and sale along busy roads expose it to environmental pollutants, particularly heavy metals released from vehicle exhaust, worn tires, engine oil leaks, and industrial dust. In addition, incomplete combustion of charcoal during grilling generates polycyclic aromatic hydrocarbons (PAHs), a group of carcinogenic organic compounds. These pollutants can settle on the meat surface or infiltrate it during roasting, yet consumers are generally unaware of these potential contaminants (Adamiec *et al.,* 2016).

Heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), and copper (Cu), along with PAHs, are known for their toxicity even at low concentrations. They persist in the environment, enter the food chain, and bioaccumulate in human tissues over time (Angon *et al.,* 2024). Prolonged exposure to lead and cadmium can impair kidney and brain function, while chromium and PAHs are linked to cancer. Excess nickel and copper can damage the liver and cardiovascular system. The continuous consumption of contaminated suya meat therefore presents a silent but significant health risk, especially in urban settings where pollution levels are high and food hygiene is poorly regulated (Ebrahimi *et al.,* 2020).

Despite growing concern about food contamination in Nigeria, there is limited scientific data on the combined presence of heavy metals and PAHs in roadside suya sold in Benin City, particularly in Ugbowo, where traffic density and open-air vending are common. Without such data, public health authorities and consumers lack a factual basis to assess potential risks or enforce food safety standards. This study addresses this gap by quantifying the levels of selected heavy metals and PAHs in suya meat sold in Ugbowo, comparing the results with international safety limits, and highlighting possible health implications for regular consumers.

### 1.4 Significance of the Study

This study is significant because it provides scientific evidence on the safety of roadside suya meat consumed daily by residents of Ugbowo and surrounding areas. By determining the concentrations of chromium, nickel, copper, lead, cadmium, and polycyclic aromatic hydrocarbons (PAHs), the research generates data that reflect the extent of environmental contamination and its possible transfer into commonly eaten foods. The findings will help public health authorities, such as NAFDAC and environmental agencies, identify pollution trends and develop appropriate control measures for street-vended foods. For consumers, the study raises awareness about the hidden risks associated with frequent consumption of suya prepared under unsanitary and high-traffic conditions, especially the exposure to carcinogenic PAHs produced from incomplete charcoal combustion. It also supports policymakers and local health inspectors with evidence-based information to guide routine monitoring and vendor education. In the academic context, the work adds to existing literature on heavy metal and PAH exposure through diet in urban Nigeria and provides baseline data for future studies on food safety and environmental pollution. Overall, this study aims to promote safer food handling practices, encourage regular screening of street foods, and strengthen public health protection in Benin City.

## 1.5 Scope of the Study

This study focuses on assessing the levels of selected heavy metals and polycyclic aromatic hydrocarbons (PAHs) in suya meat sold within Ugbowo, Benin City. Two composite samples were collected for analysis: the first was obtained from roadside vendors along major routes in Ugbowo (three different vendors combined as one sample), and the second from residential areas—specifically 19th Street, BDPA, and Edo Street in Ekosodin (three vendors combined as one sample). Each composite sample was oven-dried, homogenized, and digested using acid digestion for heavy metal analysis, while PAHs were determined using appropriate chromatographic methods. The study quantified chromium (Cr), nickel (Ni), copper (Cu), lead (Pb), cadmium (Cd), and PAHs to evaluate contamination levels and compare the results with WHO/FAO permissible limits. This scope provides insight into the potential differences in contamination between roadside and residential suya sources and highlights the environmental and health risks associated with their consumption.

## 1.6 Aim of the Study

The aim of this study is to determine the concentrations of selected heavy metals and polycyclic aromatic hydrocarbons (PAHs) in suya meat sold in different locations within Ugbowo, Benin City, to assess their potential health risks to consumers. In order to achieve this, the following objectives were to;

- collect suya meat samples from roadside and residential areas within Ugbowo, Benin City.
- copper (Cu), lead (Pb), and cadmium (Cd) using Atomic Absorption Spectrophotometry (AAS).

- determine the levels of polycyclic aromatic hydrocarbons (PAHs) in the suya samples using chromatographic techniques.
- compare the detected concentrations of heavy metals and PAHs with WHO/FAO permissible limits and evaluate possible health risks associated with regular consumption.

## 1.7 Literature Review

### 1.7.1 Suya (Grilled Beef)

#### Origin and Popularity of Suya

Suya is one of Nigeria's most popular and culturally significant street foods, prepared mainly from sliced beef coated in a spicy groundnut and pepper-based marinade, then grilled over an open flame. It originated from the Hausa-speaking northern regions but has now become a nationwide delicacy, commonly sold in urban centers such as Benin City (Olayinka *et al.,* 2008). Its rich flavor, smoky aroma, and affordability make it particularly appealing to students and young adults who view it as an accessible source of protein and a convenient late-night snack. The widespread sale of suya along roadsides, motor parks, and marketplaces enhances its availability but also exposes it to environmental hazards (Adeyeye, 2016). Most vendors operate in open environments with no protective enclosures, leaving the meat vulnerable to dust, exhaust fumes, and soot from passing vehicles. This informal setting, though culturally embedded, raises public health concerns about the safety and hygiene of suya consumed daily by thousands of people (Adamiec *et al.,* 2016).

The traditional preparation of suya is a simple and time-honored process that rarely includes modern food safety practices. The same grilling racks, knives, and trays are often used repeatedly without proper cleaning or replacement. Vendors commonly use low-quality charcoal, sometimes from treated wood or waste materials, which can release toxic residues during combustion (Eruteya and Nmehielle, 2021). Additionally, roadside locations are often chosen for their visibility and convenience rather than cleanliness or air quality. These environmental and handling conditions increase the likelihood of contamination by particulate matter and toxic metals that can adhere to or penetrate the meat during roasting.

**Environmental Exposure and Contaminant Sources**

Heavy metal contamination in suya meat can originate from multiple sources. One major contributor is **vehicular emission**, which releases lead (Pb), cadmium (Cd), nickel (Ni), and arsenic (As) into the air. These metals settle on surrounding surfaces, including exposed food. Dust particles from worn-out vehicle parts, tires, and brake linings can also contain high concentrations of heavy metals that deposit on suya displayed close to busy roads (Saulawa and Jikamshi, 2024). In addition, **soil contamination** plays a role, as particles blown from nearby waste dumps or industrial zones may contain residues of metals that eventually land on food or cooking surfaces.

Another important source of contamination is the **cooking equipment and materials**. Grilling racks made of corroded iron or coated metal can leach chromium (Cr), nickel (Ni), or copper (Cu) into meat when heated (Sultan *et al.,* 2023). Charcoal, particularly when derived from treated or polluted wood, may release trace metals during burning. Similarly, the oil, spices, and water used for marinating the meat can introduce contaminants if sourced from unregulated suppliers. Even the foil used for wrapping hot suya may contribute metallic residues when in direct contact with acidic or oily meat (Idowu *et al.,* 2023). These overlapping contamination routes make roadside suya a significant medium for human exposure to toxic metals.

### Long-Term Health Implications for Youths

While the immediate health effects of consuming contaminated suya may not be visible, the **chronic accumulation of heavy metals** poses serious long-term risks. Young consumers, especially university students and workers who frequently purchase suya, are at higher risk because they often eat it repeatedly over time. Heavy metals such as lead (Pb) and cadmium (Cd) have long biological half-lives, meaning they persist in body tissues for years (Oyewole *et al.,* 2024). Lead affects the nervous system, impairs brain development, and can cause learning difficulties, while cadmium accumulates in the kidneys, leading to renal dysfunction (Ebrahimi *et al.,* 2020). Arsenic exposure is associated with skin lesions, cancers, and cardiovascular problems, while chromium and nickel are linked to respiratory and digestive tract damage (Balali-Mood *et al.,* 2021).

These effects often develop slowly, making them difficult to trace back to food habits. A youth who eats suya several times a week may not experience immediate symptoms, but by middle age, accumulated exposure could manifest as chronic diseases such as hypertension, liver cirrhosis, or neurological decline (Mizia *et al.,* 2021). This silent toxicity highlights the hidden danger of seemingly harmless roadside delicacies. Furthermore, many consumers are unaware that exposure to multiple metals at low doses can have **synergistic effects**, where the combined toxicity is greater than the sum of individual metals. This interaction increases health risks significantly (Jaishankar *et al.,* 2014).

In public health terms, the continuous consumption of contaminated meat among youths represents a delayed epidemic. Today's dietary behavior can determine tomorrow's disease patterns. Despite the cultural and economic importance of suya, there is a pressing need to assess and regulate its safety, especially around high-traffic areas like Ugbowo in Benin City. Monitoring heavy metal concentrations in suya meat will help identify contamination patterns and inform risk management strategies. Raising awareness among consumers and training vendors on safer practices—such as relocating suya stands away from main roads, cleaning equipment regularly, and using clean charcoal—could significantly reduce exposure (Asomugha *et al.,* 2021).

Ultimately, suya remains a cherished part of Nigerian street cuisine, but the balance between taste and safety must be reconsidered. Without adequate attention to the environmental and health implications of roadside food preparation, the very delicacy that connects communities could slowly become a public health threat (Okhuebor and Izevbuwa, 2020). The youth population, being the largest group of frequent consumers, deserves better protection through scientific research, policy intervention, and education on food safety. By understanding the link between environmental contamination and human health, society can continue to enjoy suya without compromising well-being in the years to come.

## 1.8 Overview of Suya Production and Consumption in Nigeria

### Origin and Cultural Evolution of Suya

Suya holds a deep cultural and historical significance in Nigeria's food landscape. It originated among the Hausa people of Northern Nigeria, where it was traditionally prepared by itinerant butchers known as *Mai Suya* (Mizia *et al.,* 2021). The dish started as a communal delicacy made from beef or ram, spiced with locally sourced ingredients, and shared during social gatherings. Over time, suya transcended ethnic boundaries to become a unifying street food enjoyed across the country (Asomugha *et al.,* 2021).. Today, it is not just a meal but a social experience that reflects urban life, nightlife, and cultural interaction. From major cities like Lagos and Abuja to regional towns such as Benin City, suya is part of daily social routines—sold in the evenings when people gather to relax, converse, and eat.

The expansion of suya from a northern delicacy to a national favorite reflects both cultural diffusion and economic adaptation. Vendors have modified recipes to suit regional preferences, using different spice blends, levels of pepper, or meat types such as chicken, goat, or liver. Despite its simplicity, suya has become a symbol of informal entrepreneurship, supporting thousands of small-scale vendors and families. Its affordability and accessibility make it a preferred protein source for low- and middle-income earners, especially youths, students, and workers (Okhuebor and Izevbuwa, 2020). This strong socioeconomic role makes suya more than food—it represents livelihood, social bonding, and cultural identity.

**Preparation Process and Ingredients Used in Suya Making**

Suya preparation follows a traditional but structured process. Fresh meat, usually beef, is sliced into thin sheets or strips to facilitate quick roasting. The slices are skewered onto sticks—typically from local bamboo or palm fronds—and coated with a rich, dry spice blend known as *yaji*. This seasoning is the defining element of suya, composed mainly of ground peanuts, red pepper, salt, ginger, garlic, maggi (seasoning cubes), and occasionally ground crayfish or other flavor enhancers (Balali-Mood *et al.,* 2021). Some vendors add small amounts of vegetable oil to the mixture to improve texture and color when grilling.

The meat is roasted slowly over a charcoal fire, turned repeatedly to achieve even browning and smoky flavor. Charcoal is the preferred fuel because of its steady heat release and affordability, but its quality can vary widely (Ebrahimi *et al.,* 2020).. In some cases, vendors use low-grade charcoal from treated or industrial wood residues, introducing potential sources of contaminants. After grilling, the meat is often sprinkled again with *yaji* powder and served hot with sliced onions, tomatoes, cabbage, and occasionally *masa* (rice cake) or bread. The use of unregulated ingredients, reused oil, and reused charcoal makes the process simple but uncontrolled from a food safety perspective.

Unlike industrial meat products, suya lacks standardization in ingredient measurement, preparation time, or hygiene protocols. Each vendor develops a personal recipe through experience and customer feedback, leading to flavor diversity but also inconsistent safety standards. Moreover, meat preservation methods are limited; refrigeration is rare at roadside stalls, so most vendors rely on same-day preparation (Adeyeye, 2016). While this reduces spoilage risk, it also increases the likelihood of cross-contamination from handling, utensils, or environmental exposure. The entire process—though efficient and deeply traditional—exists outside any formal regulatory framework, making contamination by microbes or heavy metals a recurring concern in urban centers.

**Popularity and Socioeconomic Importance of Suya**

Suya's popularity is anchored in its cultural symbolism and accessibility. It represents the social rhythm of Nigerian urban life—often sold at night, under makeshift stalls illuminated by kerosene lamps or bulbs powered by small generators. These settings attract both the working class and students, creating a shared informal dining culture (Eruteya and Nmehielle, 2021). Its relatively low cost compared to restaurant meals makes it a staple evening snack and a common feature at social gatherings, bars, and street corners. In economic terms, suya vending is a thriving informal enterprise that sustains livelihoods, especially for young men migrating from rural to urban areas in search of income. The sector contributes to local economies through employment, raw material demand, and street commerce (Jaishankar *et al.,* 2014).

Beyond economics, suya carries symbolic and emotional value. It is associated with relaxation, friendship, and communal enjoyment. For many Nigerians, buying suya after work or study is both a reward and a social ritual. The demand pattern is particularly high among urban youths, who form the largest consumer base. This strong consumption trend highlights suya's embeddedness in modern Nigerian culture—bridging traditional cuisine with contemporary lifestyle (Laoye *et al.,* 2025).

**Environmental Conditions During Preparation and Sale**

Most suya vendors operate in open-air environments near roadsides, motor parks, and busy junctions. These locations guarantee visibility and patronage but expose the meat to environmental pollutants such as dust, vehicle exhaust, and particulate matter (Adamiec *et al.,* 2016). The grills are typically positioned just a few meters from moving traffic, where airborne contaminants can easily settle on exposed food. The lack of enclosures or protective barriers allows free interaction between meat, air, and surrounding dust. In addition, the use of locally fabricated metallic grills, often rusted or coated with paint residues, can introduce trace metals like chromium and copper during heating (Mititelu *et al.,* 2025).

Hygiene practices also vary widely. Vendors handle money, raw meat, and cooked suya simultaneously, sometimes without washing hands or sanitizing utensils. Water used for cleaning is often stored in open containers and reused multiple times (Mizia *et al.,* 2021). During grilling, high heat may kill microbes, but it cannot remove heavy metals already deposited on the meat surface. The combined effects of poor air quality, contaminated surfaces, and unregulated cooking materials make roadside suya an easy target for environmental contamination.

Despite these risks, consumers rarely express concern about hygiene or contamination. The immediate appeal of aroma and taste overshadows invisible threats. This underscores the paradox of suya—its charm lies in its simplicity and street authenticity, yet those same attributes heighten the potential for exposure to harmful contaminants (Okhuebor and Izevbuwa, 2020). Recognizing these environmental realities is key to developing safe practices that preserve both the cultural and nutritional value of suya without compromising public health.

## Sources of Heavy Metal Contamination in Food

Heavy metal contamination in food is a growing public health issue, especially in developing regions where environmental controls are weak and food processing takes place in informal settings. These metals—such as lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), arsenic (As), and nickel (Ni)—enter food systems from both **natural** and **anthropogenic** sources. While trace metals exist naturally in soil, water, and air, human activities have significantly increased their concentrations, creating multiple pathways for contamination (Gelaye, 2024).

## Natural and Anthropogenic Sources

Natural sources include weathering of metal-rich rocks, volcanic activity, and leaching from soil minerals. In such cases, trace amounts of metals can enter plants, water, and the food chain through absorption and bioaccumulation (Briffa *et al.,* 2020). However, the dominant contributors today are anthropogenic. **Traffic emissions** are a major source in urban areas—vehicles release lead, cadmium, and nickel through fuel combustion, tire wear, and brake linings. These metals are deposited as fine dust on surrounding soil and air, where they easily settle on exposed foods like roadside suya (Balali-Mood *et al.,* 2021).

**Industrial waste** also contributes heavily. Effluents from metal fabrication, battery production, and paint industries often contain high concentrations of lead, chromium, and copper. When improperly disposed, they contaminate surface water and soil, which later serve as indirect sources for crop and livestock contamination (Jaishankar *et al.,* 2014). In addition, **soil dust** around busy roads or industrial zones carries resuspended metal particles that can settle on food surfaces during preparation or sale. Cooking utensils and equipment are another critical source: rusted or coated grills, metallic skewers, and aluminum foils can leach metals into food when heated, especially in acidic or oily conditions (Olayinka *et al.,* 2008). Charcoal derived from treated wood or waste materials may also release trace metals during combustion, exposing the meat to additional contamination during grilling.

**Pathways of Contamination in Meat**

Meat can become contaminated at different stages—during processing, grilling, or exposure to open air. In processing, contamination can occur if the animal is raised in a polluted environment. Livestock grazing on contaminated pastures or drinking polluted water may accumulate metals in their tissues (Okhuebor and Izevbuwa, 2020). When such meat is used for suya preparation, the contamination is already inherent before cooking begins.

During grilling, **cross-contamination** occurs through contact with cooking surfaces and tools. Metallic grills or skewers, if corroded, release chromium and nickel when exposed to high heat (Oluwakemisola, 2025). Oils, spices, and water used in seasoning may contain residues from contaminated sources, while charcoal combustion releases airborne particulates that can settle back on the roasting meat (Oyewole *et al.,* 2024).

Once the meat is cooked, **atmospheric deposition** becomes the main pathway. Roadside vendors commonly grill and display suya near heavy traffic areas where dust and exhaust fumes are prevalent. These airborne particles adhere easily to the oily surface of the hot meat. Since most stalls lack protective coverings, the food remains exposed throughout sale hours. Even the wrapping materials—especially low-grade aluminum foil or newspaper—may introduce further contamination when in direct contact with greasy, hot meat (Tchounwou *et al.,* 2014).

The combined effect of these contamination routes means that heavy metals can enter food at multiple points before consumption. Unlike biological contaminants that can be killed by heat, metals are not destroyed during cooking; they persist and accumulate in human tissues with repeated intake (Sultan *et al.,* 2023). This persistence underscores the need for stricter monitoring of food handling environments, better regulation of roadside food vending, and public awareness on the hidden risks of environmental pollution on dietary safety.

## Toxicological Effects of Selected Heavy Metals

Heavy metals are naturally occurring elements with high atomic weight and density that can be toxic even at low concentrations. When ingested through contaminated food, they can accumulate in human tissues over time, causing serious physiological and biochemical disturbances. The degree of toxicity depends on the type of metal, concentration, exposure duration, and the body's ability to metabolize or excrete it. In this section, six key metals—Chromium (Cr), Nickel (Ni), Arsenic (As), Copper (Cu), Lead (Pb), and Cadmium (Cd)—are discussed with emphasis on their physicochemical characteristics, biological effects, and health implications from dietary exposure.

### Chromium (Cr)

Chromium exists mainly in two oxidation states: trivalent chromium ($Cr^{3+}$) and hexavalent chromium ($Cr^{6+}$). $Cr^{3+}$ is an essential micronutrient involved in carbohydrate and lipid metabolism, while $Cr^{6+}$ is highly toxic and carcinogenic. It is a steel-gray metal with a high melting point (1907°C) and corrosion resistance, which explains its use in stainless steel production and metal plating.

Exposure to $Cr^{6+}$ through contaminated food or air can lead to oxidative stress and DNA damage. Studies have shown that $Cr^{6+}$ crosses cell membranes easily and is reduced to $Cr^{3+}$

inside cells, releasing reactive oxygen species (ROS) that damage cellular proteins and nucleic acids (Peydayesh *et al.,* 2022). Chronic ingestion has been linked to liver dysfunction, gastric ulcers, and kidney damage. Epidemiological studies in industrial regions show an increased risk of lung and gastrointestinal cancers among individuals exposed to high chromium levels (Saulawa and Jikamshi, 2024).

Chromium tends to accumulate in the liver, kidneys, and bones. Although $Cr^{3+}$ absorption from food is relatively low (0.4–2%), $Cr^{6+}$ is far more bioavailable. Repeated exposure through contaminated meat or water can lead to gradual buildup in tissues, especially in populations consuming food cooked or handled with corroded metallic utensils.

**Nickel (Ni)**

Nickel is a silvery-white transition metal used widely in stainless steel, coins, and batteries. It has moderate electrical conductivity and is resistant to corrosion. In trace amounts, nickel may play a role in enzyme activity, but in excess, it becomes toxic to humans (Mazi *et al.,* 2023).

Nickel exposure occurs mainly through inhalation or ingestion of contaminated food, water, or air. It binds strongly to proteins and DNA, causing cellular stress. Acute ingestion results in nausea, vomiting, and abdominal pain, while long-term exposure is associated with dermatitis, lung fibrosis, and carcinogenesis. Nickel compounds are classified as Group 1 carcinogens by the International Agency for Research on Cancer (IARC). Dietary exposure to nickel can alter calcium and iron metabolism, potentially leading to anemia and impaired bone growth (Laoye *et al.,* 2025).

Nickel is moderately absorbed through the gastrointestinal tract and accumulates in the lungs, kidneys, and bones. Studies have found elevated nickel concentrations in the blood and urine of individuals consuming food cooked on nickel-containing utensils or exposed to industrial emissions (Eruteya and Nmehielle, 2021). Its elimination is slow, allowing it to persist in the body and exert cumulative toxic effects over time.

**Copper (Cu)**

Copper is an essential trace element required for hemoglobin synthesis, iron metabolism, and antioxidant defense systems. It is a reddish metal with excellent electrical conductivity and is widely used in wiring, plumbing, and cookware. However, excessive copper intake can lead to toxic effects (Idowu *et al.,* 2023).

While the human body tightly regulates copper levels, chronic exposure through contaminated food, water, or utensils can overwhelm these controls. High copper intake causes oxidative damage through the Fenton-like reaction, producing free radicals that harm lipids and DNA (Royer and Sharman, 2020). Acute symptoms include nausea, vomiting, abdominal cramps, and diarrhea, whereas chronic exposure results in liver cirrhosis, neurological impairment, and in severe cases, Wilson's disease—a genetic disorder leading to copper accumulation in organs. Studies have shown that copper released from corroded cooking utensils or piping can significantly increase dietary intake.

Copper is stored mainly in the liver, brain, and kidneys. Unlike other toxic metals, small amounts of copper are essential, but once the storage capacity of the liver is exceeded, free copper ions circulate and cause oxidative stress (Royer and Sharman, 2020). Prolonged exposure to elevated levels can disrupt the balance of other trace metals like zinc and iron, amplifying its toxic effects.

**Lead (Pb)**

Lead is one of the most hazardous environmental toxins. It is a soft, bluish-gray metal used historically in paints, gasoline, and pipes. It has no known biological role in the human body and is toxic at any concentration.

Lead interferes with multiple biochemical processes. It mimics calcium, allowing it to enter cells and disrupt signaling pathways. Lead inhibits several enzymes involved in heme synthesis, leading to anemia. In children, even low exposure levels impair cognitive development, reduce IQ, and cause behavioral problems (Flora *et al.,* 2012). Adults may experience hypertension, infertility, and kidney dysfunction. Long-term exposure through contaminated meat, dust, or utensils is particularly harmful because lead binds to bone tissue and remains there for decades.

Lead's bioaccumulation is slow but persistent. Approximately 90% of total body lead is stored in bones and teeth. During stress, illness, or pregnancy, stored lead can be released into the bloodstream, posing risks to developing fetuses and infants (Wani *et al.,* 2015). Research in Nigeria and other developing nations consistently reports elevated lead levels in street-vended foods, highlighting its significance as a dietary contaminant.

**Cadmium (Cd)**

Cadmium is a soft, silver-white metal obtained mainly as a by-product of zinc refining. It is used in batteries, pigments, and coatings but is extremely toxic to humans even at trace levels.

Cadmium exposure primarily occurs through food and tobacco smoke. Once ingested, it binds strongly to proteins, especially metallothionein, forming stable complexes that accumulate in organs. Acute cadmium poisoning causes nausea, vomiting, and abdominal pain, while chronic exposure leads to kidney damage, bone demineralization, and reproductive toxicity (Mititelu *et al.,* 2025). It disrupts calcium metabolism, resulting in bone fragility and the condition known as *Itai-Itai disease*, historically observed in Japan. Cadmium also induces oxidative stress, impairs DNA repair, and promotes carcinogenesis.

Cadmium has an exceptionally long biological half-life—10 to 30 years—and accumulates mainly in the kidneys and liver. Its absorption increases with dietary deficiencies of iron, calcium, and zinc. Even small daily intakes can lead to harmful accumulation over time. Research in Nigeria has reported cadmium levels in roadside foods exceeding WHO permissible limits, posing long-term health risks to frequent consumers.

**Polycyclic Aromatic Hydrocarbons (PAHs)**

Polycyclic aromatic hydrocarbons (PAHs) are a group of organic compounds composed of two or more fused benzene rings formed primarily during incomplete combustion of organic materials such as charcoal, wood, or oil. In food, they are produced when meat fat drips onto hot charcoal, creating smoke that contains PAHs, which then deposit on the meat surface. The high temperatures used during suya grilling—combined with open flames and continuous smoke exposure—promote the formation of these compounds. The intensity and duration of roasting, type of fuel, distance between meat and fire, and fat content of the meat all influence the level of PAH contamination. Charcoal made from treated wood or mixed waste materials has been shown to produce higher PAH levels compared to clean hardwood sources.

More than a hundred PAHs have been identified in grilled or smoked foods, but a few are of major toxicological concern due to their strong mutagenic and carcinogenic properties. Commonly detected compounds in grilled meat include benzo[a]pyrene, fluoranthene, anthracene, chrysene, and benzo[b]fluoranthene. Among these, **benzo[a]pyrene** is often used as a marker compound for assessing total PAH contamination because of its high carcinogenic potency. Once ingested, PAHs undergo metabolic activation in the liver by cytochrome P450 enzymes, producing reactive intermediates that bind to DNA and cause mutations. Chronic exposure can lead to genetic alterations, oxidative stress, and the development of cancers affecting the lung, liver, and gastrointestinal tract.

The World Health Organization (WHO) and the United States Environmental Protection Agency (EPA) classify several PAHs, including benzo[a]pyrene, as **Group 1 carcinogens**—agents with sufficient evidence of carcinogenicity in humans. Food safety authorities across Europe and Africa have established regulatory limits for PAHs in smoked and grilled meat, typically not exceeding 2 µg/kg for benzo[a]pyrene and 12 µg/kg for the sum of four key PAHs (benzo[a]pyrene, benzo[a]anthracene, benzo[b]fluoranthene, chrysene). Regular consumption of meat contaminated with PAHs poses cumulative health risks, especially in urban settings where roadside grilling occurs near vehicular emissions and poor air quality.

Given the popularity of suya and its open-fire preparation method, assessing PAH contamination is as important as heavy metal evaluation. Monitoring these compounds provides critical information for understanding the chemical safety of street-vended meat and supports the development of safer cooking and fuel-handling practices.

**General Considerations on Bioavailability and Health Impacts**

The bioavailability of heavy metals depends on several factors, including chemical form, solubility, and interaction with food components. Metals in ionic or soluble forms are more readily absorbed through the gastrointestinal tract. Fat-rich foods like grilled meat can enhance the absorption of lipophilic metal compounds (Scutarașu and Trincă, 2023). Once absorbed, these metals circulate in the bloodstream, bind to proteins, and deposit in target organs such as the liver, kidney, brain, and bones.

Prolonged dietary exposure leads to **bioaccumulation**, where metals build up faster than they can be excreted. This accumulation triggers oxidative stress, enzyme inhibition, and interference with essential minerals. The resulting health outcomes—ranging from anemia and kidney failure to cancer and neurotoxicity—are often delayed, making detection and prevention difficult (Balali-Mood *et al.,* 2021). Continuous monitoring of food products, especially roadside meat like suya, is essential to safeguard public health against chronic heavy metal exposure.

**Previous Studies on Heavy Metals in Meat and Street-Vended Foods**

Several studies have assessed the presence of heavy metals in meat and street-vended foods across Nigeria and other countries, revealing concerning trends in contamination levels. In Nigeria, research by Saulawa and Jikamshi (2024) found elevated concentrations of lead (Pb) and cadmium (Cd) in suya and roasted meat sold in urban markets of southeastern cities, often exceeding WHO permissible limits. Similarly, Amalo and Princess (2018), reported detectable levels of chromium (Cr) and nickel (Ni) in suya samples from Ilorin and Lagos, attributing the contamination to the use of contaminated charcoal, metal grills, and vehicular emissions during roadside sales. Studies in other African countries, such as Ghana and Kenya, have shown comparable findings, where Pb and As levels in grilled meat exceeded international safety standards. These results indicate that the open-air preparation and handling of suya make it vulnerable to environmental pollutants and contaminated raw materials.

International research supports these observations. In India, Mwove et al. (2023) found Cd, Pb, and Cu residues in street-vended meat and fish products, suggesting similar contamination routes from exhaust fumes and metal utensils

Comparatively, the concentration levels of Pb and Cd in Nigerian suya have been found to range between 0.3–2.5 mg/kg and 0.05–0.8 mg/kg, respectively—values often above permissible limits of 0.1 mg/kg and 0.05 mg/kg set by FAO/WHO. Such exposures pose long-term risks, including neurological impairment, kidney damage, and carcinogenic effects (Laoye *et al.,* 2025). The cumulative ingestion of contaminated meat contributes significantly to the dietary intake of toxic metals, especially in urban populations where suya is a daily meal. Collectively, past studies highlight the urgent need for routine surveillance, safer processing environments, and enforcement of food safety standards to reduce public health risks associated with heavy metal exposure through meat consumption.

**Analytical Methods for Determining Heavy Metals in Food**

Determining heavy metals in food requires careful coordination of sampling, digestion, and instrumental analysis. The reliability of results depends on how well these steps are executed and monitored. In assessing heavy metals such as chromium, nickel, arsenic, copper, lead, and cadmium in suya meat, the method must combine accuracy, sensitivity, and practicality for a meat-based matrix.

**Common Analytical Techniques**

Several analytical techniques are used to detect heavy metals in food, with Atomic Absorption Spectrophotometry (AAS), Inductively Coupled Plasma–Optical Emission Spectroscopy (ICP-OES), Inductively Coupled Plasma–Mass Spectrometry (ICP-MS), and X-Ray Fluorescence (XRF) being the most common (El Hosry *et al.,* 2023). AAS remains the most widely used in food analysis because it offers a balance of precision, affordability, and ease of operation. Flame AAS is ideal for metals such as copper and lead at moderate concentrations, while Graphite Furnace AAS provides higher sensitivity for trace metals like cadmium and nickel. Hydride generation AAS enhances detection for arsenic. ICP-OES allows simultaneous multi-element detection and offers better speed and dynamic range (Karpiuk *et al.,* 2016). ICP-MS, the most advanced, provides ultra-trace sensitivity and isotopic analysis but is costly and requires high technical expertise. XRF is non-destructive and fast but less sensitive for trace-level meat analysis.

## 1.9 Sample Preparation and Digestion

Sample preparation is a key determinant of analytical accuracy. Meat samples are first homogenized to achieve uniformity and prevent sampling bias. Representative portions are collected using clean, acid-washed tools and stored in airtight containers under refrigerated conditions. Before analysis, samples are digested to break down the organic matrix and release metals into solution. Microwave-assisted acid digestion using concentrated nitric acid and hydrogen peroxide is preferred because it offers efficient oxidation, minimal contamination, and consistent recovery (Rohde *et al.,* 2015). Open-vessel digestion on a hot plate is also used but has a higher contamination risk. After digestion, the samples are filtered, diluted with deionized water, and transferred to volumetric flasks for analysis.

### Quality Control and Calibration

Quality assurance ensures that analytical results are accurate and reproducible. Calibration involves preparing multi-point standard curves from certified stock solutions, while matrix effects can be minimized using standard addition or matrix-matched standards. Procedural blanks, duplicates, and spiked samples are analyzed alongside the meat samples to monitor precision and recovery. Certified reference materials (CRMs) for meat provide benchmarks for method validation (Cortese *et al.,* 2020). Acceptable recovery for heavy metal analysis generally ranges between 80–120%, with relative standard deviation (RSD) below 10%. For trace-level analysis, detection and quantification limits must be established using blank signal variability and low-level spiked samples.

### Advantages of AAS in Trace Metal Quantification

Atomic Absorption Spectrophotometry remains a preferred method for trace metal determination in food due to its cost efficiency, simplicity, and proven reliability. AAS systems are more affordable and accessible to many research laboratories compared to ICPbased instruments. For studies like this one, which focuses on a specific set of metals, AAS provides the required selectivity and sensitivity, particularly with the graphite furnace or hydride generation modes. The technique's long-standing regulatory acceptance and availability of standardized protocols make it ideal for reproducible and comparable results. Although AAS analyzes one element at a time, its accuracy and established methodology make it a dependable option for public health-related investigations.

**Operational Considerations**

For this project, the most suitable workflow would involve microwave-assisted acid digestion followed by AAS analysis. Graphite Furnace AAS would be used for cadmium and lead, Flame AAS for copper and chromium, and Hydride AAS for arsenic. Strict adherence to contamination control, calibration verification, and the use of CRMs would ensure reliable data. While advanced methods like ICP-MS offer superior sensitivity, AAS provides a practical, accurate, and validated approach for determining heavy metals in roadside suya meat. This balance between technical efficiency and resource availability makes it the optimal choice for this study.

**Standards and Guidelines for Heavy Metal Levels in Food**

The assessment of heavy metals in food is guided by international and national standards designed to protect consumers from chronic toxicity. Agencies such as the World Health Organization (WHO), Food and Agriculture Organization (FAO), the European Union (EU), and Nigeria's National Agency for Food and Drug Administration and Control (NAFDAC) have established permissible limits for heavy metals in various food types, including meat. These limits represent the maximum concentrations that can be tolerated without adverse health effects over a lifetime of consumption.

According to WHO/FAO guidelines, the maximum allowable concentrations in meat are approximately Cr (0.1 mg/kg), Ni (0.5 mg/kg), As (0.1 mg/kg), Cu (20 mg/kg), Pb (0.1 mg/kg), and Cd (0.05 mg/kg). The EU Food Safety Authority adopts similar benchmarks but tends to impose stricter limits for toxic metals such as lead and cadmium due to their bioaccumulative nature and high toxicity. The EU regulation (EC No. 1881/2006) specifies limits of 0.1 mg/kg for Pb and 0.05 mg/kg for Cd in meat and meat products (Kamaly and Sharkawy, 2023). NAFDAC, aligning with the Codex Alimentarius standards and WHO recommendations, also enforces comparable thresholds for meat products sold in Nigeria. However, due to limited routine surveillance and testing infrastructure, compliance monitoring remains inconsistent, particularly in the informal street food sector.

These standards are designed based on toxicological data and the concept of Provisional Tolerable Weekly Intake (PTWI), which defines the amount of a contaminant that can be ingested weekly over a lifetime without appreciable risk. For instance, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) established PTWI values of 0.025 mg/kg body weight for lead and 0.007 mg/kg for cadmium (Saulawa and Jikamshi, 2024). Exceeding these limits may result in accumulation in vital organs such as the liver, kidney, and brain, leading to chronic toxicity and potential carcinogenic effects. Metals such as arsenic and chromium have dual characteristics, where certain forms (e.g., Cr(III)) are essential micronutrients, while others (e.g., Cr(VI), As(III), As(V)) are toxic even at low concentrations.

Regulatory standards, however, are only effective when coupled with active enforcement and public awareness. Street-vended foods like suya, though popular and economically important, are rarely subjected to systematic testing. The roadside environment exposes the meat to contamination from vehicle emissions, dust, and metallic utensils, increasing the risk of exceeding safe metal levels (Rane, 2011). Weak enforcement mechanisms, inadequate laboratory capacity, and lack of awareness among vendors contribute to potential health risks, especially for consumers who eat such foods frequently. Strengthening local food surveillance programs through NAFDAC and municipal health authorities is therefore critical.

Regular monitoring of roadside suya for heavy metals and adherence to WHO/FAO and NAFDAC standards would help identify unsafe practices and reduce public exposure to toxic metals. Public education campaigns targeting vendors and consumers are equally necessary to promote hygienic preparation and minimize contamination risks. Aligning local regulations with global safety benchmarks ensures consumer protection and fosters accountability in Nigeria's expanding street food industry (Ebrahimi *et al.,* 2020).

# CHAPTER TWO

# MATERIALS AND METHODS

## 2.1Materials

### **2.1.1** Apparatus

- Analytical balance
- Hot plate
- Digestion flasks
- Volumetric flasks (50 mL and 100 mL)
- Beakers (100 mL and 250 mL)
- Measuring cylinders
- Funnels and filter paper (Whatman No. 42)
- Mortar and pestle
- Oven (for drying samples)
- Soxhlet extractor
- Rotary evaporator
- Silica gel column
- Atomic Absorption Spectrophotometer (AAS)
- Gas Chromatography–Mass Spectrometer (GC–MS)
- Aluminum foil and polyethylene bottles

### 2.1.2 Reagents

- Concentrated nitric acid ($HNO_3$)
- Hydrogen peroxide ($H_2O_2$)

- Distilled water
- Hexane
- Dichloromethane
- Standard stock solutions of Cr, Ni, Cu, Pb, and Cd
- Silica gel (for column purification)
- Certified PAH standards

## 2.2 Methodology

### 2.2.1 Sample Collection

Suya samples were collected from selected locations within Ugbowo, Benin City, to represent areas with varying exposure to environmental pollution. Two composite samples were obtained for analysis. The first sample was collected from roadside vendors operating along major roads in Ugbowo, where vehicular traffic is high; meat portions purchased from three different vendors were combined to form one representative roadside sample. The second sample was collected from residential areas, specifically from vendors located on 19th Street, BDPA, and Edo Street in Ekosodin, with portions from three vendors also combined to form a single residential sample. Each sample was wrapped in clean aluminum foil, labeled accordingly, and transported immediately to the laboratory for preparation and analysis to prevent external contamination.

### 2.2.2 Sample Preparation

In the laboratory, the suya samples were first unwrapped and cut into smaller pieces using clean stainless-steel knives. The samples were then oven-dried at about 105°C until a constant weight was reached to remove moisture. After drying, each sample was ground into a fine powder using a clean mortar and pestle and mixed thoroughly to make it uniform. The powdered samples were stored in clean, labeled airtight containers to avoid contamination and kept at room temperature until they were used for digestion and analysis.

### 2.2.3 Digestion and Analytical Methods

The prepared suya samples were digested to break down the organic matter and release the target elements into solution for analysis. About 2 g of each powdered sample was weighed into a clean digestion flask, and 10 mL of concentrated nitric acid ($HNO_3$) was added. The mixture was heated on a hot plate at 120°C until the brown fumes disappeared, followed by the addition of 2 mL of hydrogen peroxide ($H_2O_2$) to complete the oxidation. The digestion continued until a clear solution was obtained. The digest was then cooled, filtered through Whatman No. 42 filter paper, and diluted to 50 mL with distilled water in a volumetric flask. The resulting solution was stored in labeled polyethylene bottles and used for the determination of heavy metals using Atomic Absorption Spectrophotometry (AAS). Separate portions of the suya samples were prepared and analyzed for polycyclic aromatic hydrocarbons (PAHs) using Gas Chromatography–Mass Spectrometry (GC–MS).

### 2.2.4 Determination of Heavy Metals (AAS)

Heavy metal concentrations, including chromium (Cr), nickel (Ni), copper (Cu), lead (Pb), and cadmium (Cd), were determined using an Atomic Absorption Spectrophotometer (AAS). Each digested sample solution was aspirated into the AAS flame, where the metals absorbed specific wavelengths of light corresponding to their atomic spectra. Standard solutions of known concentrations for each metal were prepared and used to calibrate the instrument. The absorbance readings obtained from the samples were compared with those of the standards to calculate the concentration of each metal in milligrams per kilogram (mg/kg) of dry weight. To maintain accuracy, blank determinations and quality control samples were analyzed alongside the test samples.

### 2.2.5 Determination of PAHs (GC–MS)

The concentration of polycyclic aromatic hydrocarbons (PAHs) in the suya samples was determined using Gas Chromatography–Mass Spectrometry (GC–MS). About 2 g of each homogenized sample was extracted with a mixture of hexane and dichloromethane using a Soxhlet apparatus for six hours. The extract was concentrated and purified through silica gel column chromatography to remove interfering substances. One microliter of the cleaned extract was injected into the GC–MS equipped with a capillary column and operated in electron impact ionization mode. The chromatographic conditions, including temperature program and carrier gas flow rate, were optimized for PAH detection. Identification of individual PAHs was based on retention times and mass spectra compared with certified standards, and their concentrations were quantified using calibration curves.

# CHAPTER THREE

# RESULTS AND DISCUSSION

## 3.1 RESULTS

**Table 3.1: Concentration of Heavy Metals in Suya Samples from Residential and Express Road Areas**

| S/N | Metal | Express Road (mg/kg) | Residential Area (mg/kg) | WHO/FAO Limit (mg/kg)* | Remark |
|---|---|---|---|---|---|
| **1** | Lead (Pb) | 4.348 | 5.002 | 0.1 | Above limit |
| **2** | Chromium (Cr) | <0.001 | <0.001 | 1.0 | Within limit |
| **3** | Copper (Cu) | 1.635 | 0.654 | 0.5 | Above limit (residential) |
| **4** | Cadmium (Cd) | 4.381 | 3.988 | 0.05 | Above limit |
| **5** | Nickel (Ni) | 9.578 | 5.230 | 0.5 | Above limit |

**Table 3.2: POLYNUCLEAR AROMATIC HYDROCARBONS (mg/kg)**

| COMPONENTS | EXPRESS ROAD | RESIDENTIAL AREA |
|---|---|---|
| **Naphthalene** | 0.000 | 0.000 |
| **2-methylnaphthalene** | 0.000 | 0.000 |
| **Acenaphthylene** | 0.000 | 0.000 |
| **Acenaphthene** | 0.000 | 0.000 |
| **Fluorene** | 0.000 | 0.000 |
| **Phenanthrene** | 0.000 | 0.000 |
| **Anthracene** | 0.000 | 0.000 |
| **Fluoranthene** | 0.000 | 0.000 |
| **Pyrene** | 0.000 | 0.000 |
| **Chrysene** | 0.000 | 0.000 |
| **Benz[a]anthracene** | 0.000 | 0.000 |
| **benzo[b]fluoranthene** | 0.000 | 0.000 |
| **benzo[k]fluoranthene** | 0.000 | 0.000 |
| **Benzo[a]pyrene** | 0.000 | 0.000 |
| **Indeno[1,2,3-cd]pyrene** | 0.000 | 0.000 |
| **Dibenz[a,h]anthracene** | 0.000 | 0.000 |

### 3.2 DISCUSSION

The concentrations of selected heavy metals in suya samples from both residential and express road areas are shown in Table 3.1. Lead (Pb), cadmium (Cd), copper (Cu), and nickel (Ni) were detected in varying amounts, while chromium (Cr) was below the detection limit (<0.001 mg/kg) in both samples. The results indicate that both sampling areas contained measurable levels of toxic metals, although the distribution varied by location.

Lead concentration was slightly higher in the residential sample (5.002 mg/kg) compared to the express road sample (4.348 mg/kg). This difference is likely due to greater exposure to vehicular emissions and road dust, which are common sources of airborne lead contamination in high-traffic zones. The concentrations recorded for Pb in both areas exceed the WHO/FAO permissible limit of 0.1 mg/kg for meat, suggesting potential health risks for regular consumers.

Cadmium (Cd) levels were high in both samples, with 4.381 mg/kg in the express road and 3.988 mg/kg at the residential area. These values are far above the acceptable limit of 0.05 mg/kg, indicating significant contamination that could be linked to environmental pollution or the use of contaminated charcoal and metal grilling utensils. Chronic cadmium exposure is known to cause kidney and liver damage, making these results a concern for food safety.

Copper (Cu) was present at moderate levels, with higher concentration in the express road (1.635 mg/kg) than the residential area (0.654 mg/kg). Since copper can leach from metal grills or utensils, differences may reflect variations in the materials used by vendors. Although copper is an essential trace element, excess intake may cause gastrointestinal irritation or liver problems.

Nickel (Ni) recorded the highest overall concentration among the metals analyzed—9.578 mg/kg in the express road and 5.230 mg/kg at the residential area. These values exceed the

WHO limit of 0.5 mg/kg, indicating serious contamination. Nickel likely originated from corroded grilling surfaces or dust deposition during open-air roasting.

The concentrations of polycyclic aromatic hydrocarbons (PAHs) in the suya samples from both the express road and residential areas are presented in Table 3.2. The GC–MS results showed that all sixteen priority PAHs, including naphthalene, phenanthrene, fluoranthene, pyrene, chrysene, benzo[a]pyrene, and indeno[1,2,3-cd]pyrene, were not detected in any of the analyzed samples. This indicates that the PAH levels were below the detection limit of the instrument (0.000 mg/kg) for both sampling locations.

The absence of detectable PAHs suggests that the grilling process under the sampled conditions produced minimal smoke or incomplete combustion products capable of generating PAHs. This may be attributed to the use of well-dried charcoal, moderate roasting temperature, or adequate ventilation during meat preparation. It is also possible that the exposure time of the meat to smoke was short, reducing the likelihood of PAH deposition. Similar observations have been reported by other studies where proper combustion and controlled heating reduced PAH formation in grilled meat.

Although PAHs were not detected in this study, their formation remains a potential risk in roadside suya prepared under high heat or smoky conditions. PAHs are known carcinogenic and mutagenic compounds formed during incomplete combustion of organic matter, and prolonged exposure through food consumption can pose health hazards. Therefore, continuous monitoring of suya and similar grilled foods is important to ensure consumer safety, particularly in urban areas with variable fuel quality and cooking practices.

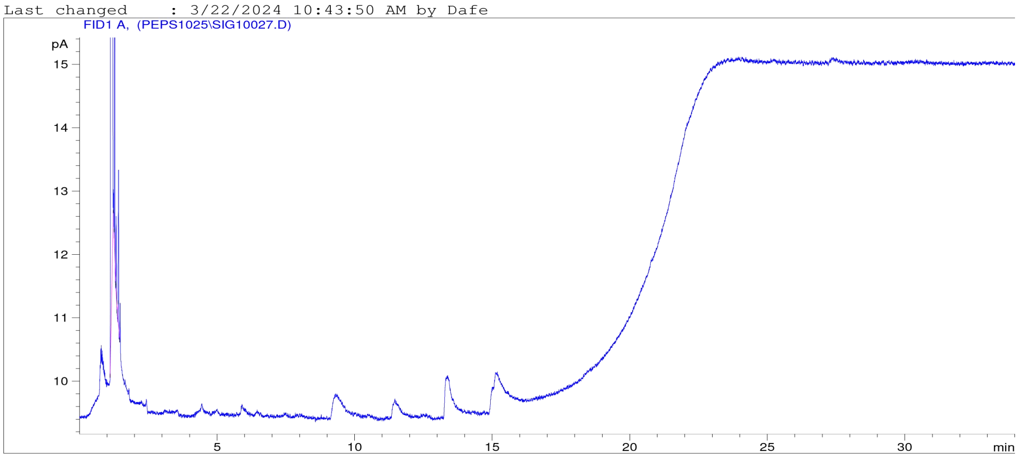


**Figure 3.1:** GC–MS Chromatogram of PAH Analysis for Suya Sample from Express Road, Ugbowo

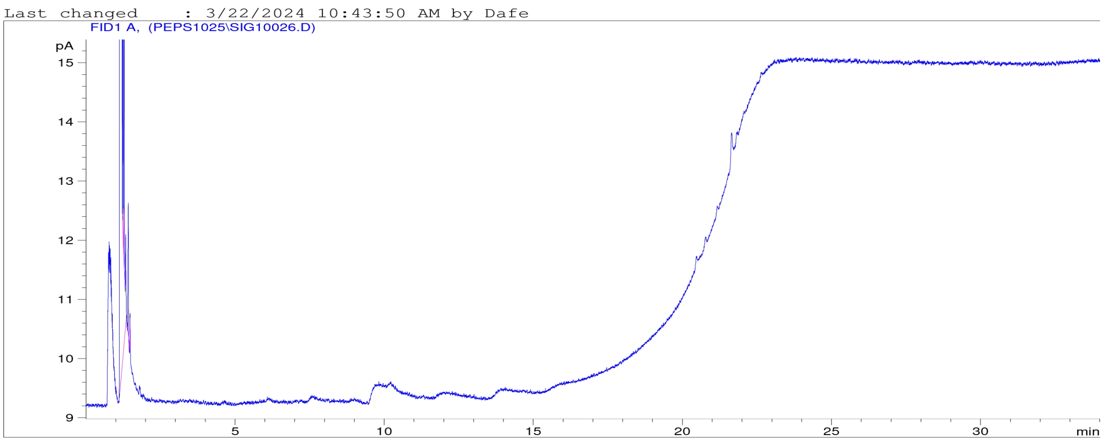


**Figure 3.2:** GC–MS Chromatogram of PAH Analysis for Suya Sample from Residential Area, Ugbowo

### 3.3 CONCLUSION

The study revealed that suya meat sold in Ugbowo, Benin City, contains significant levels of heavy metals, particularly lead, cadmium, copper, and nickel, all exceeding WHO/FAO safety limits. These metals likely originated from vehicle emissions, metal grilling equipment, and dust exposure during open-air preparation. Chromium was below detection, while all sixteen priority PAHs were not detected, indicating minimal formation of carcinogenic compounds during grilling. The absence of PAHs suggests that the roasting process and fuel used were relatively clean, but the elevated heavy metal concentrations pose a serious public health concern for regular consumers. Continuous consumption of such contaminated meat could lead to bioaccumulation and long-term toxic effects. The study recommends regular monitoring of street-vended foods, stricter environmental control around vending sites, and improved hygiene and fuel handling practices to reduce contamination and protect consumer health.

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