

**UNIVERSITY OF GHANA**

**COLLEGE OF BASIC AND APPLIED SCIENCES**

**DEPARTMENT OF NUTRITION AND FOOD SCIENCE**

**EXPOSURE ASSESSMENT OF SOME HEAVY METALS (ARSENIC, LEAD,  
CADMIUM, MERCURY, COPPER AND ZINC) IN LOCALLY PRODUCED RICE  
SOLD IN ACCRA METROPOLIS**

**BY**

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**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN  
PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER  
OF PHILOSOPHY FOOD SCIENCE DEGREE**

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**INTEGRI PROCEDAMUS**

## DECLARATION

This is to certify that this thesis is the results of research by Desmond Asante Karikari under supervision towards the award of MPhil degree in the Department of Nutrition and Food Science.

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## ABSTRACT

Rice is the second-most consumed cereal in Ghana. However, human activities such as mining and excessive use of agro-chemicals in some farming areas have the potential to pollute rice with heavy metals, and compromise food safety. The objective of this study was to assess the levels and risk of heavy metals in locally produced rice sold in Accra Metropolis. Also, the quantity and consumption pattern of rice in Accra was also surveyed using structured questionnaire. A total of 385 consumers who consented participated in the survey. Information collected included sex, age, and body weight as well as frequency and quantity of rice consumed. Children's consumption information was collected from parents or caregivers. Thirty samples of local rice (uncooked) were sampled from markets and analyzed for heavy metals (arsenic, lead, cadmium, mercury, copper, and zinc) using ICP-MS. Exposure assessment was conducted using the U.S. EPA method. The estimated intake, carcinogenic and non-carcinogenic risk were determined. Survey results showed participants weighed between 60 and 69 kg, consumed an average of 496.36 grams of rice per week and 221.67 grams of rice per day. Children consumed averagely 58.33 grams of rice per day and 142.43 grams of rice per week and they weighed between 21 and 30 kg. Concentration of heavy metals in all the rice samples were below the upper limit permitted by Codex. However, the consumption of local rice was found to be associated with carcinogenic and non-carcinogenic hazards in both adults and children from the outcome of the risk assessment. Exposure to arsenic, lead, and cadmium were of primary concern for the children whilst for the adults, it was arsenic and lead. The health risk of exposure to heavy metals should be publicized and education intensified in order to protect public health.

## DEDICATION

I dedicate my dissertation work to my late dad, Mr. Kwabena Asante Karikari and the rest of my family. A special feeling of gratitude for you all.



## ACKNOWLEDGEMENT

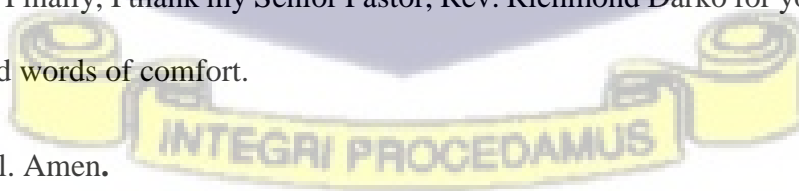
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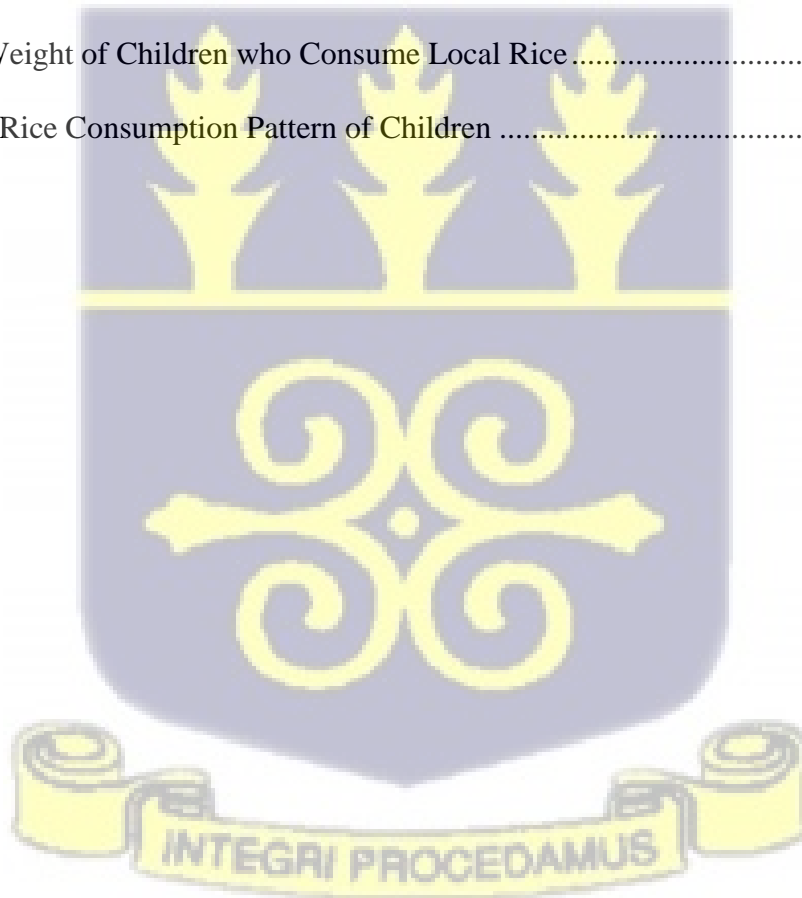
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## LIST OF ABBREVIATIONS

AB	Ashanti Brown
As	Arsenic
ANOVA	Analysis of Variance
AW	Ashanti White
Cd	Cadmium
CR	Cancer Risk
CRM	Certified Reference Material
Cu	Copper
DHHS	Department of Health and Human Services
DNA	Deoxyribonucleic Acid
EDI	Estimated daily intake
EFSA	European Food Safety Authority
EPA	Environmental Protection Agency
EU	European Union
EWI	Estimated weekly intake
FAO	Food and Agriculture Organization
FAPAS	Food Analysis Performance Assessment

HI	Hazard Index
IARC	International Agency for Research on Cancer
iAs	Inorganic Arsenic
ICP-MS	Inductive Coupled Plasma Mass Spectrophotometer
IPC	Infection prevention and control
LDL	Low-density lipoprotein
HDL	High-density lipoprotein
Hg	Mercury
NB	Northern Brown
NW	Northern White
MoFA	Ministry of Food and Agriculture
MT	Megatonne
Pb	Lead
pH	power of hydrogen
PTFE	Polytetrafluoroethylene
PTWI	Permitted tolerable weekly intake
RDA	Recommended Daily Allowance
RfD	Reference dose



RNA	Ribonucleic Acid.
USDA	United States Department of Agriculture
US FDA	United States Food and Drugs Authority
VB	Volta Brown
VW	Volta White
WHO	World Health Organization
Zn	Zinc



## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background

Rice is a commonly consumed staple meal that makes up a sizable percentage of the diets of more than half of the world's population. (Danso-Abbeam et al., 2014; Nurshad, 2019). In the last 30 years, the global rice consumption climbed by 40%. (Anang et al., 2011). Rice, Ghana's main staple meal, is the second-most significant cereal after corn (MoFA, 2020; USDA, 2018). For both city and rural consumers, it provides a convenient food (Anang et al., 2011; Tomlins et al., 2003).

Ghana has experienced a significant change in rice consumption patterns and levels (MoFA, 2020). Due to its comparatively easy preparation and delectable recipes, its consumption has expanded in the nation along with population expansion, and it is quickly becoming a major component of the diet in many Ghanaian families (Anang et al., 2011; Armah & Aboagye, 2020; USDA, 2018). Urbanization, expatriate community, entrepreneurial middle class, tourism sector, and an increase in women working outside the home are boosting its demand (Armah & Aboagye, 2020; USDA, 2018).

In recent years, there has been concerns about heavy metal contamination of rice crops (Gomah et al., 2019) and this led to several countries prioritizing the implementation of food safety practices (Salem, 2021). However, exposure to heavy metals continue to pose a significant threat to food safety (Naujokas et al., 2013a).

Heavy metals are defined by Holleman & Wiberg Nils (1985) as metals with specific weights greater than 5 gcm<sup>-3</sup> or, as stated by Ferguson (1990), as metallic elements with a comparatively high density in contrast to water. Heavy metals with negative health consequences when exposure

is not minimized include arsenic (As), lead (Pb), cadmium (Cd), mercury (Hg), copper (Cu), and zinc (Zn) (Duffus, 2001). Most plant and animal tissues may accumulate heavy metals, which have extended half-lives and are deadly when they do. (Otitoju et al., 2014).

The presence of heavy metals in the soil might be due to natural occurrences or anthropogenic activity (such as mining, extraction, careless rubbish disposal, and various agricultural practices) (Otitoju et al., 2014; Teymori et al., 2014). In the course of mining, for instance, heavy metals may occasionally be released into the environment and transported by air and water to other areas (Engwa et al., 2019). Plant death has been seen when heavy metal concentrations are high (Carolyn & Aqilah, 2014).

Arsenic (As) is abundant in the environment, occurs everywhere, and can easily infiltrate the food chain or food supply through tainted soil, water, or air (Nguyen et al., 2019a; US FDA, 2020). Its risks are well established, and it affects humans in a variety of ways (Liao et al., 2018). According to reports, arsenic exposure may affect more people than previously thought and contribute to a greater number of chronic diseases (Naujokas et al., 2013a).

Although lead (Pb) is a naturally occurring chemical, human activities like mining and manufacture have the potential to introduce it into the environment (Tchounwou et al., 2012a). It is extremely dangerous and carcinogenic by the Environmental Protection Agency (Jaishankar et al., 2014; EPA, 1988). According to Papanikolaou et al., 2005, lead poisoning in humans has the most negative effects on the hemopoietic, neurological, reproductive, and urinary tract systems. Acute exposure might result in nausea, vomiting, headaches, hypertension, stomach pain, renal failure, lethargy, sleeplessness, arthritis, hallucinations, and vertigo (Jaishankar et al., 2014).

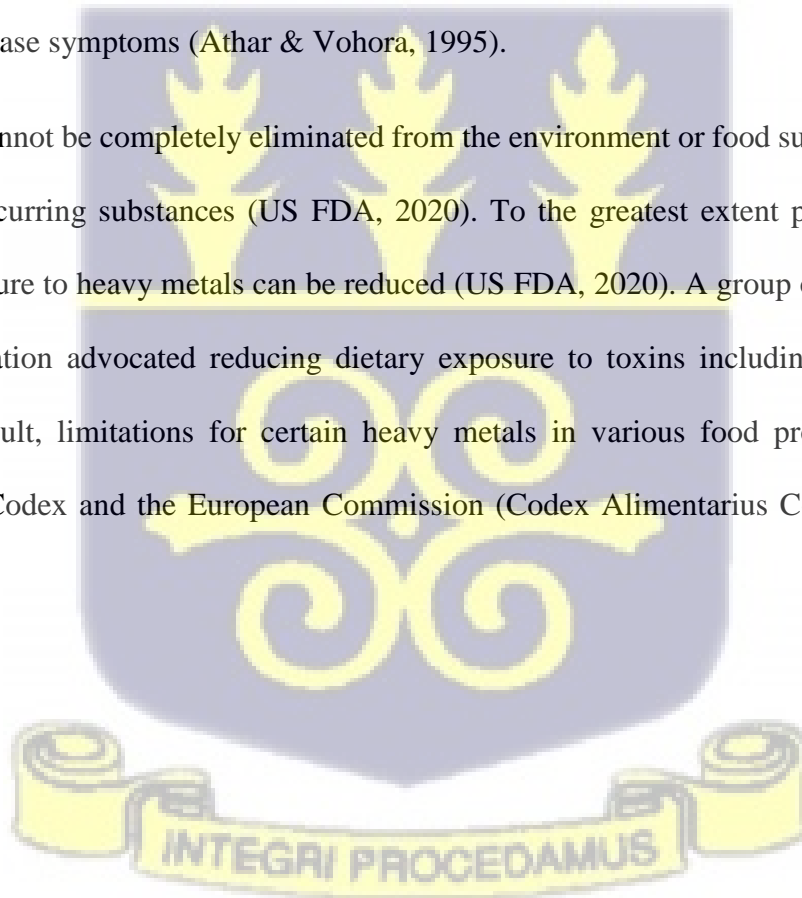
Industrial activities and cadmium smelters release cadmium into sewage sludge, fertilizers, and groundwater, where it can stay in soils and sediments for decades before being absorbed by plants (Unaegbu et al., 2016). The primary source of exposure to cadmium is certain crops, such as rice, which can accumulate significant levels of the metal if cultivated in cadmium-contaminated soil (WHO, 2019). Cadmium and its compounds can lead to cancer in humans, according to the International Agency for Research on Cancer (IARC), which made this claim in 1993. People exposed to cadmium have an increased risk of developing leukaemia, high blood pressure, osteoporosis, renal illness, urinary bladder, pancreatic, breast, and prostate cancers (Satoh et al., 2002).

As a bio accumulative substance, mercury is exceedingly hazardous (Jaishankar et al., 2014). Mercury contamination is mostly caused by human activities like agriculture, municipal and industrial wastewater discharges, mining, and cremation (Chen, 2012). Intestinal issues, acrodynia disorders, and harm to the brain and central nervous system have all been connected to mercury (Gomah et al., 2019). In addition, it can accumulate in the thyroid, raising the risk of autoimmune diseases and resulting in contact dermatitis (Gallagher et al., 2012; Caravati et al., 2008).

An essential micronutrient needed for biological activity is copper (Cu) (Harvey & Mcardle, 2008; Tchounwou et al., 2008). Clinical signs of a deficit, such as anemia, hypercholesterolemia, and skeletal abnormalities, demonstrate that it is essential for humans (Harvey & Mcardle, 2008). Despite this, high copper exposure has been linked to cell damage in humans, leading to Wilson disease (Tchounwou et al., 2008). Additionally, a surplus of such metals damages cells and tissues, which has several negative effects and causes human diseases. According to Tchounwou et al., there is relatively little difference in copper content between beneficial and detrimental effects (2008).

Zinc is a necessary heavy metal in the human body, and its homeostasis reflects a balance between dietary zinc absorption and zinc loss from the body (Kumar Sharma & Agrawal, 2004; Wuana & Okieimen, 2011). Zinc is essential for the proper functioning of many organ systems, as well as for growth, development, and tissue repair (Codex Alimentarius Commission, 2016). Excessive zinc exposure, on the other hand, can be harmful and have pathological consequences (Naseri et al., 2015a). Acute zinc toxicity in humans can result in vomiting, dehydration, sleepiness, lethargy, electrolyte imbalance, abdominal discomfort, nausea, poor motor coordination, and renal failure (Kumar Sharma & Agrawal, 2004). An excessive intake of zinc over time boosts the risk of anemia, pancreatic damage, low-density lipoprotein (LDL) cholesterol elevation, and worsening Alzheimer's disease symptoms (Athar & Vohora, 1995).

Heavy metals cannot be completely eliminated from the environment or food supply because they are naturally occurring substances (US FDA, 2020). To the greatest extent possible, however, consumer exposure to heavy metals can be reduced (US FDA, 2020). A group of experts on food chain contamination advocated reducing dietary exposure to toxins including arsenic (EFSA, 2009). As a result, limitations for certain heavy metals in various food products have been established by Codex and the European Commission (Codex Alimentarius Commission, 2016; EFSA, 2009).



## 1.2 Rationale for the study

Over the past 10 years, the consumption of rice has increased significantly as a huge portion of consumers switched from other staples to rice. (Nurshad, 2019; Tomlins et al., 2003) Rice consumption per capita increased from 24 kg in 2012/2013 to 35 kg in 2016/2017 (GSS, 2018). Also, rice expenditure per capita increased from 3.3 times that of maize in 2012/2013 to 4.1 times in 2016/2017 (Ragasa et al., 2020). This continuous increase in rice consumption is because of factors such as change in consumer habits, population growth, urbanization and increase in consumers' wealth (Anang et al., 2011; MoFA, 2020). Consumers in urban areas account for 70% of national consumption (MoFA, 2020).

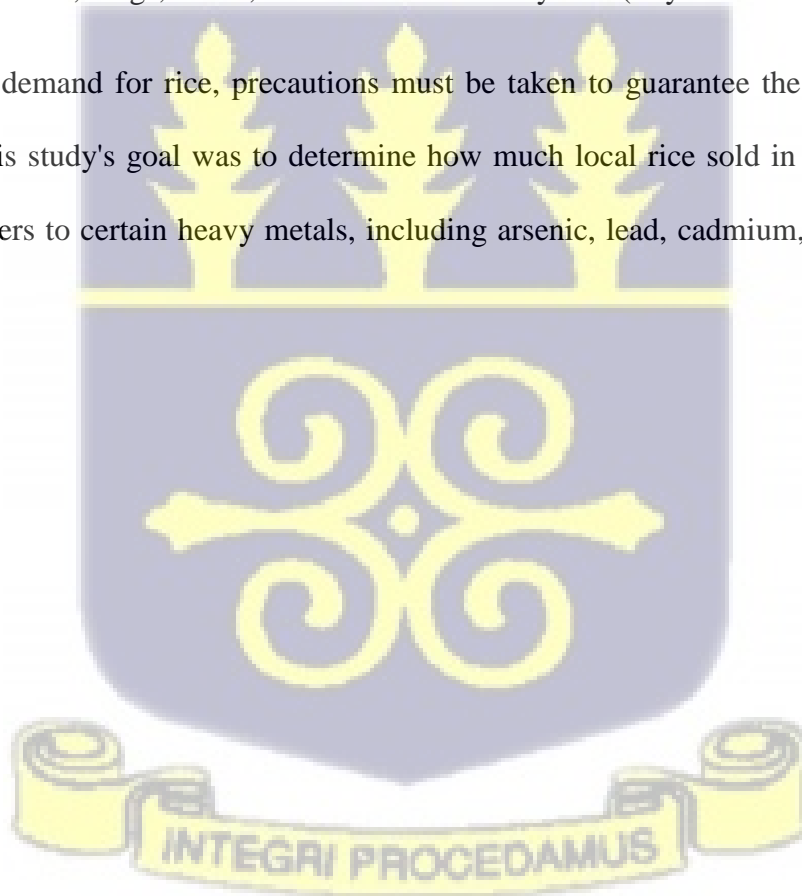
Ghana's domestic rice production reached 450,000 MT in 2017/2018, up from 390,000 MT in 2016/2017 owing to excellent weather circumstances and other major production factors (MoFA, 2020; USDA, 2018). A factor that has revamped domestic rice production in Ghana is the government's commitment to boost rice output by setting expansion targets through the introducing of new high yielding and disease resistant rice cultivars, and the use of low-cost water management measures (USDA, 2018; (MoFA, 2020). In addition, was the establishment of the Ghana Rice Inter-Professional Body (GRIB) as one of the efforts by the government to revamp the local rice industry (Diako et al., 2010). Moreover, production and consumption of local rice is growing in popularity in Ghana for various reasons, including affordability and a countrywide goal of increasing local production to strengthen the economy. (Danso-Abbeam et al., 2014).

Additionally, some rice farms are located near mining operations, which causes the soil and water used to irrigate rice fields to also absorb the mine's effluent, which is contaminated with several heavy metals. For instance, the MoFA reports that between 2020 and 2021, the Central Region's rice output grew dramatically (from 12,308 metric tonnes to 16,246 metric tonnes). The districts

that produce most of the region's rice are Gomoa East, Assin Central, Assin North, Assin South, and Twiffo Attimorkwa (MoFA, 2022). The Pra river, a significant body of water utilized for irrigation in this region, has over time been extensively poisoned with heavy metals because of unlawful mining. Also, using too many pesticides raises the concentrations of several heavy metals in the soil and groundwater (Kalita et al., 2018; Teymori et al., 2014).

Rice contamination by heavy metals endangers consumers, therefore there is the need to ensure its safety (Naseri et al., 2015). Most heavy metals, including cadmium, lead, and arsenic, have been identified as carcinogenic (Cubadda et al., 2003; EPA, 1988; IARC, 2012), with effects on the liver, kidneys, bladder, lungs, bones, and central nervous system (Teymori et al., 2014).

Given the huge demand for rice, precautions must be taken to guarantee the public's health is safeguarded. This study's goal was to determine how much local rice sold in Accra Metropolis exposes consumers to certain heavy metals, including arsenic, lead, cadmium, mercury, copper, and zinc.

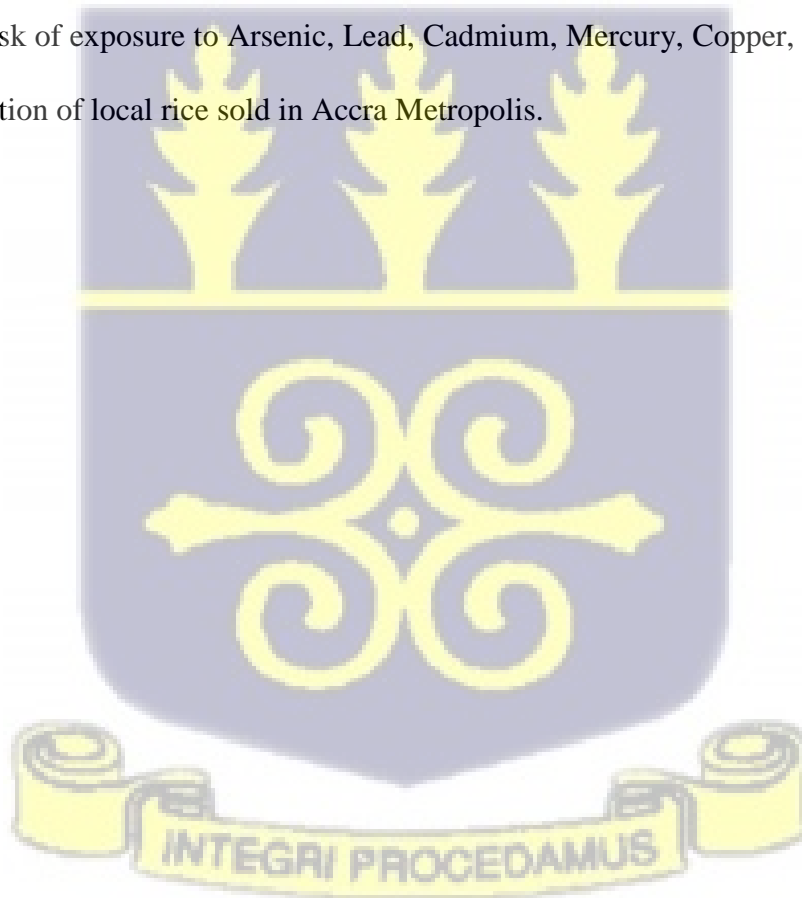


### 1.3 Main Objective

The primary goal of this study was to evaluate the risk of exposure to various heavy metals (Arsenic, Lead, Cadmium, Mercury, Copper, and Zinc) in locally produced rice sold in the Accra Metropolitan Area.

#### 1.3.1 Specific Objectives

- i. Determine extent of local rice consumption by consumers in Accra Metropolis.
- ii. Determine the concentrations of Arsenic, Lead, Cadmium, Mercury, Copper, and Zinc in local rice sold at markets in Accra Metropolis.
- iii. Assess risk of exposure to Arsenic, Lead, Cadmium, Mercury, Copper, and Zinc from the consumption of local rice sold in Accra Metropolis.



## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Rice and its Benefits

The Gramineae family (Poaceae) of grass plants includes rice (Tripathi et al., 2011). Other grains like maize, sorghum, and millet as well as tubers and roots like potatoes, yams, and cassava have long held sway in regions of the world where rice has gained popularity (Danabal et al., 2021). Rice is the main food consumed by most people in underdeveloped nations (Roy et al., 2013). For example, it has been stated that Africa has experienced the greatest rise in rice consumption during the past few decades (Danabal et al., 2021). Since the beginning of civilization, rice has provided life-sustaining nourishment throughout the humid regions of Asia and, to a lesser extent, West Africa (Roy et al., 2013).

Rice (*Oryza sativa*) is among the species of cultivated rice which originated from Asia (*O. rufipogon*, and *O. glaberrima*) but originally it originated from Africa (*O. barthii*) (Cordero-Lara, 2020). Rice is categorised according to its form (Dzudzor, 2013). Rough rice, also known as paddy rice, refers to rice that has not been processed and hence retains the hull and bran layer (Dzudzor, 2013). Brown rice is rice that has had the hull removed but still has the bran layer adhering to it (Dzudzor, 2013). The term "milled rice" refers to rice that has had the hull and bran coating removed (Dzudzor, 2013). The grain becomes refined as the degree of milling increases as the bran layer is eliminated further (Dzudzor, 2013). Rice can be classified as polished or unpolished depending on the degree of milling. The sensory qualities of milled rice are superior, but it has fewer vitamins, minerals, fats, and fiber (Abbas et al., 2017).

Rice is a good source of calories and protein, and it also has a lot of zinc and niacin (FAO, 2006) which are all essential for body development. Rice is an important grain as it accounts for more

than one-fifth of all calories consumed by humans globally (Pateriya et al., 2021). Rice's protein quality (66%) is only slightly lower than that of oats (68%) but higher than that of whole wheat (53%) and corn (49 %) (Roy et al., 2013). Among the cereals, rice is without a doubt the most energy-dense (Roy et al., 2013). In other words, rice crops produce more food energy per hectare than wheat and maize, based on mean grain yield (Roy et al., 2013).

Rice, which is low in sodium and fat and cholesterol-free, helps to keep blood pressure in check (Roy et al., 2013). Rice contributes significantly to agricultural GDP (Gross Domestic Product) of the Ghanaian economy (Suleman & Sarpong, 2012). Rice is used to make infant foods, snack foods, breakfast cereals, beer, fermented products, and rice bran oil in the industrial world (Roy et al., 2013). However, rice has been shown to accumulate more metals than other cereal grains (Williams et al., 2007).

## **2.2 Rice Production in Ghana**

A variety of habitats, including irrigated, rainfed lowland, deep water, upland, and tidal wetlands, are suitable for the growth of rice (International Rice Research Institute, 1984). When compared to other crops, rice crops require at least two to three times as much water as other cereals (Kumar Pandey et al., 2015). Conventional rice cultivation methods (transplanted rice) require typically 2500 liters of water to produce 1 kilogram of rough rice (Bouman et al., 2007). In Ghana, rice is one of the most important cereals grown in terms of agricultural land because it makes up roughly 19 percent of the country's grain production (Danso-Abbeam et al., 2014).

Rice is grown across all sixteen regions of Ghana, including the interior Savannah zone, the high rain forest zone, the semi-deciduous rain forest zone, and the coastal Savannah zone, in all the key biological and climatic zones (Amanor-Boadu, 2012; Oteng, 2020). Nearly 80% of the country's

total rice production and 73% of its total production area in 2010 were produced in Ghana's Northern, Upper East, and Volta regions, which are also its most populous (Asravor et al., 2019; Danso-Abbeam et al., 2014; Donkoh & Awuni, 2011). Rice is typically planted once a year, however, in rare cases where irrigation is available, producers may plant two crops per year. Planting takes place in July/August in the Northern and Upper East, while harvest takes place in October/November (USDA, 2018).

Governments in Ghana have reportedly made numerous attempts throughout the years to boost domestic rice output, according to Donkoh et al. (2012). One instance is the implementation of numerous irrigation projects, including the Veve, Afife, Kpong, Tanoso, Ashaiman, Tono, Dawhenya, Weija, Bontanga, and Aveyime. The government has also implemented efforts to increase rice output because of worries expressed by the Coalition for African Rice Development (CARD) about tripling rice production in Sub-Saharan African nations in ten years (Suleman & Sarpong, 2012). As a result, the country set a goal of becoming West Africa's leading rice producer by 2015 (Suleman & Sarpong, 2012). This led to the establishment of the Fievie Rice Projects in the country's Volta Region (Suleman & Sarpong, 2012).

Ghana's domestic rice production for MY2020/21 was expected to be 500,000 MT, an increase of about 6% from the MY2019/20 estimate of 470,000MT (USDA, 2020). This shows strong growth in the domestic rice sector and the continuation of Ghana's recent upward production trajectory (USDA, 2020). However, it has been reported that commercial growers use a lot of pesticides (Anang & Amikuzuno, 2015). Some of these pesticides contain heavy metals (Kalita et al., 2018). Due to the use of arsenic-contaminated water for irrigation and the many processes that result in its mobilization, which affect the agricultural system and cause crop plant uptake of the element, levels of heavy metals like arsenic have increased in soils (Kalita et al., 2018). According to Xu et

al. (2008), rice has a greater translocation factor (TF) for metals such As (0.8) than other cereals like wheat (0.1) and barley (0.2).

### 2.3 Types of Local Rice

Branded and unbranded local rice are the two categories that make up the market for local rice (Spring Agro Industries Limited, 2021). Large-scale domestic farmers and processors frequently supply branded types, which are usually premium fragrant long grain varieties (Spring Agro Industries Limited, 2021). Most supermarkets and shopping malls sell locally produced rice under brand names (Ayeduvor, 2018). Some branded domestic types are now almost as popular as foreign ones (Spring Agro Industries Limited, 2021). Most of the unbranded local rice sold by vendors at traditional open markets is obtained from the country's primary rice-producing regions in the Eastern and Northern Regions of Ghana (Ayeduvor, 2018; Spring Agro Industries Limited, 2021).

According to Ayeduvor's (2018) market research, most rice vendors in urban traditional open marketplaces sell their product by the bowl and the sack. Most of the time, the producing area is used to identify rice types in local markets (Ayeduvor, 2018). However, nothing is known about the native rice types that are marketed in the market (Ayeduvor, 2018). Tamale brown rice, Tamale white rice, Tamale agra rice, Hohoe brown rice, Hohoe white rice, Kumasi brown rice and Kumasi white rice (Kpong) are the types of local rice reported in the literature (Ayeduvor, 2018). Much of the local rice sold at markets in Accra come from the Volta Region (Hohoe area) and Tamale in the Northern Region (Ayeduvor, 2018).

## 2.4 Rice consumption in Ghana

Rice consumption patterns and levels in Ghana have rapidly changed especially among city dwellers who constitute about 70% of the national consumption (Ayeduvor, 2018; Donkoh et al., 2012; MoFA, 2020). Because of this, rice has become Ghana's most important cereal food crop after maize (Amanor-Boadu, 2012; Ayeduvor, 2018). MY2020/21 consumption is expected to be 1.42 million MT, up 1% from Post's MY 2019/20 estimate of 1.4 million MT (USDA, 2020).

Rice consumption in Ghana has increased in tandem with population growth, and rice is increasingly becoming a staple in many Ghanaian households due to its ease of preservation and preparation as well as palatable recipes (Ayeduvor, 2018; Ragasa et al., 2020; USDA, 2020). Rising urbanization, a burgeoning expat population, a middle-class that is entrepreneurial, a quickly increasing tourism industry, and an increase in households where both couples work outside the home are all factors that are causing the demand for rice to increase (MoFA, 2020; USDA, 2020).

The features of rice that impact cooking, such as cooking time, water absorption ratio, elongation ratio, swelling capacity, and amylose content, have also raised demand for rice (Ayeduvor, 2018). The growth of eateries and fast-food joints in significant cities and towns has also increased demand for rice (Donkoh & Awuni, 2011; MoFA, 2020; USDA, 2020). With Ghana's population presently projected by the Ghana Statistical Service to reach above 30 million in 2020, rice consumption is predicted to increase proportionately. Per capita consumption of rice is now estimated to be approximately 48 kg per year (USDA, 2020).

## 2.5 Heavy Metals

Heavy metals are naturally occurring substances with large atomic weights and densities at least five times that of water (Tchounwou et al., 2012b). Since they are present in a variety of environmental matrices in concentrations ranging from parts per billion to less than 10 parts per million, heavy metals are sometimes referred to as trace elements (Kabata-Pendias, 2000). They are widely dispersed throughout the environment because of numerous industrial, domestic, agricultural, medicinal, and technological uses (Tchounwou et al., 2012b). As a result, questions have been raised about their potential effects on the environment and human health. The dose, route, chemical species, as well as the exposed person's age, gender, heredity, and nutritional condition, all have an impact on the toxicity of these substances (Tchounwou et al., 2012b). Every heavy metal is recognized to have unique physical and chemical features that give rise to certain toxicological modes of action (Tchounwou et al., 2012b). The heavy metals Arsenic, Lead, Cadmium, Mercury, Copper, and Zinc are the subject of this investigation.

### 2.5.1 Arsenic (As)

Arsenic, although possessing properties that make it both a metal and a non-metal, is chemically classified as a metalloid but is most frequently referred to as a metal (ATSDR, 2007; Martinez et al., 2011). It is an abundant element that is present in modest concentrations in almost all environmental matrices (ATSDR, 2007). Metallic arsenic is another name for the solid, steel-gray material known as elemental arsenic (ATSDR, 2007). Despite this, the environment typically contains arsenic, oxygen, chlorine, and sulphur (ATSDR, 2007). The bulk of organic and inorganic arsenic compounds are granules that are colorless or white and do not evaporate (ATSDR, 2007). They often lack a distinct flavor and fragrance (ATSDR, 2007). As a result, figuring out whether arsenic is in food, water, or the air can be difficult (ATSDR, 2007).

As a result of arsenic's natural occurrence in the ground, it may enter the air, water, and land through wind-blown dust and can enter bodies of water through runoff and leaching (ATSDR, 2007). Variable amounts of it have been found in the soil, water, fuels, marine life, and air (Smedley & Kinniburgh, 2002). The underlying geology of the area affects arsenic levels, according to a US FDA report from 2020. Furthermore, they appear in volcanic explosions (ATSDR, 2007). Due to pollution from mining, fracking, coal-fired power plants, arsenic-treated timber, and arsenic-containing herbicides, arsenic levels are increased in some places (Tchounwou, Patlolla, et al., 2003; US FDA, 2020). It may do this by evaporating in the rain or by discharging industrial waste into lakes, rivers, and subterranean water sources (ATSDR, 2007).

Under reducing circumstances, arsenite predominates, while in oxygen-rich environments, arsenate is the most stable species. Most of the forms of arsenic dissolved in water are inorganic (WHO, 2001). Organo-arsenic species are created by the biotransformation of toxic inorganic arsenic (iAs) molecules, which subsequently enter biosynthetic pathways to create the roughly one hundred chemicals prevalent in nature (Taylor et al., 2017). Since the beginning of time, large ingested doses of inorganic arsenic (above 60,000 ppb in water) have been known to be fatal (ATSDR, 2007). Arsenic's solubility and oxidation state, as well as several other inherent and extrinsic characteristics, all have a significant impact on how dangerous it is (Centeno et al., 2005).

Arsenic toxicity is regulated by the dosage, frequency, and duration of exposure, the biological species, age, and gender, in addition to personal susceptibilities, genetics, and dietary variables (Abernathy et al., 1999). Numerous cases of human arsenic poisoning have been linked to exposure to inorganic arsenic (Tchounwou et al., 2012b). Inorganic arsenic (iAs) is related with an increased risk of long-term health problems (EFSA, 2009). When consumed, small amounts of inorganic arsenic (between 300 and 30,000 parts per billion in water) may irritate the stomach and intestines,

causing symptoms including nausea, vomiting, and diarrhoea (ATSDR, 2007). Ingestion of inorganic arsenic also causes blood vessel damage, which can result in bruising, an irregular heartbeat, decreased production of red and white blood cells, which can lead to weariness, and poor nerve activity, which can result in "pins and needles" feelings in the hands and feet (ATSDR, 2007).

Inorganic arsenic compounds can damage many organs even when taken in small amounts over time (Al-Saleh et al., 2017). The most noticeable side effect of long-term oral exposure to inorganic arsenic is probably a pattern of skin problems (ATSDR, 2007; Chung et al., 2014; Hughes et al., 2011; Naujokas et al., 2013b; Steinmaus et al., 2013; US FDA, 2020). Some of them include blotches of darker skin and the development of tiny "corns" or "warts" on the palms, soles, and chest. These changes are typically accompanied by adjustments to the skin's blood vessels (ATSDR, 2007). Skin cancer is another possibility (ATSDR, 2007; Steinmaus et al., 2013; Zaldivar, 1974). It has also been demonstrated that long-term inorganic arsenic exposure has an impact on the vascular system (ATSDR, 2007). Blackfoot Disease, which causes a gradual loss of circulation in the hands and feet and finally results in necrosis and gangrene, is the most striking of these consequences (ATSDR, 2007). Recent research shows that exposure to inorganic arsenic is more hazardous and can have detrimental effects on health than exposure to organic arsenic (US FDA, 2020). Arsenic in drinking water is known to induce lung cancer, and long-term oral exposure to the substance results in the development of respiratory malignancies (ATSDR, 2007). Human carcinogenicity is assigned to inorganic arsenic. For instance, the United States Department of Health and Human Services (DHHS) classifies inorganic arsenic as a human carcinogen (ATSDR, 2007).

The International Agency for Research on Cancer (IARC) classified arsenic as a Group 1 carcinogen since there is enough evidence to connect its exposure to humans with cancer (IARC, 2012). Inorganic arsenic is a human carcinogen through oral and inhalation routes, according to the Environmental Protection Agency (EPA), which has assigned it to cancer classification Group A. (ATSDR, 2007). The underlying molecular processes of arsenic's well-known negative impacts on health remain poorly understood (Martinez et al., 2011). Little is known about the carcinogenicity of arsenic at levels that raise risks for immunological problems, cancer (Gilbert-Diamond et al., 2013; Tchounwou, Patlolla, et al., 2003), diabetes (Navas-Acien et al., 2005; Sung et al., 2015), ischemic heart disease, and peripheral vascular disease (Abhyankar et al., 2016). Eating inorganic arsenic is therefore harmful at all quantities, even if it cannot be avoided.

### **2.5.2 Lead (Pb)**

In tiny proportions, lead is an element that naturally occurs in the earth's crust (EPA, 2022; Tchounwou et al., 2012b). Because of human activities including the burning of fossil fuels, mining, and manufacturing, lead and lead compounds can be found in the air, soil, and water (Martin & Griswold, 2009; Tchounwou et al., 2012b). Since lead looks like calcium, the majority of it is absorbed and deposited in children's and adults' bones, where it can stay for decades (Adeti, 2015). Despite the fact that lead may take on many different chemical forms, it does not break down in the environment. Lead-containing particles can move via the air, water, and soil (ATSDR, 2020).

The major source of lead in soils that are not affected by other nearby non-air sources (such as dust from degrading leaded paint) is often atmospheric deposition (ATSDR, 2020). Lead is continually transferred between the air, water, and soil via natural physical and chemical processes like

weathering, runoff, precipitation, dry deposition of dust, and stream/river movement (ATSDR, 2020). But it appears that soil and sediments are significant Lead sinks (ATSDR, 2020). Most soils strongly absorb lead, which reduces the rate of leaching. The pH and composition of the soil are the primary determinants of Lead solubility, mobility, and phytoavailability in that environment (ATSDR, 2020). Reducing conditions and high chloride concentration are some factors that exacerbate Lead mobility in soil (ATSDR, 2020).

Nearly all the body's organs and systems might be harmed by lead (EPA, 2022). It is hazardous to people and animals and causes health issues because it is not required by the human body in any quantity (ATSDR, 2020). (EPA, 2022). Since more than 2,000 years ago, lead's toxicity to humans has been known and is not in question (ATSDR, 2020). Lead poisoning is one of the most often observed accidental hazardous heavy metal exposures in kids and the main factor in single-metal toxicity in kids (Bronstein et al., 2011). Due to its ability to prevent or mimic the actions of calcium and interact with proteins, lead is one of the main factors that contribute to poisoning (ATSDR, 2020). Numerous ways exist through which lead binds to biological molecules, reducing their capacity to function (Tchounwou et al., 2012b). An enzyme's structure changes, and its activity decreases when lead binds to the sulfhydryl and amide groups (Tchounwou et al., 2012b). Lead can also compete with important metallic cations for binding sites, affecting the activity of enzymes or how important cations like calcium are transported (Flora et al., 2007). Reactive oxygen species (ROS) are produced as a result of lead ingestion, which destroys cells (Hermes-Lima et al., 1991). The International Agency for Research on Cancer (IARC) has classified lead as potentially human carcinogenic due to a large body of data in animals and insufficient evidence in humans (IARC, 2014). (ATSDR, 2020).

### 2.5.3 Cadmium (Cd)

Cadmium is a highly poisonous metal (Martin & Griswold, 2009). This element becomes toxic over time because of its accumulation (Gomah et al., 2019). It is a by-product of zinc and lead mining and smelting (Jaishankar et al., 2014). Cadmium is also obtained from used batteries (Faroon et al., 2013). It is found in soils and rocks, as well as coal and mineral fertilizers (Jaishankar et al., 2014; Martin & Griswold, 2009; Tchounwou et al., 2012b). Pure cadmium is a delicate, silver-white metal (Faroon et al., 2013). Cadmium sulphate and chloride are soluble in water (Faroon et al., 2013).

Cadmium's harmful effects are widely established (Ogabiela et al., 2011). If inhaled or ingested, cadmium can be fatal since it is a risky digestive and lung irritant (Tchounwou et al., 2012b). Symptoms such as nausea, stomach discomfort, burning feeling, vomiting, salivation, muscle cramps, vertigo, shock, loss of consciousness, and convulsions may emerge 15 to 30 minutes after acute consumption (Baselt, 2020). Acute cadmium poisoning can also cause gastrointestinal tract erosion, lung, hepatic, or renal dysfunction depending on the route of poisoning (Baselt, 2020).

Although the specific mechanisms of cadmium toxicity are unknown, it has been hypothesized that cadmium toxicity primarily damages cells by producing reactive oxygen species (ROS), which causes single-strand DNA damage and prevents the production of nucleic acids and proteins (Mitra, 1984; Stohs & Bagchi, 1995). When compared to other metals that cause cancer, cadmium is a weak mutagen (J. B. Smith et al., 1989).

Studies (Dally & Hartwig, 1997; Suszkiw et al., 1984; Thévenod & Jones, 1992) have shown that cadmium interferes with signal transduction pathways by forming inositol polyphosphate, increasing the concentration of free calcium in the cytoplasm of several cell types, and blocking calcium channels. At lower concentrations (1-100 M), cadmium binds to proteins, inhibits DNA

repair, promotes protein degradation, up-regulates the expression of cytokines and proto-oncogenes like c-fos, c-jun, and c-myc, and induces the expression of numerous genes, including metallothioneins, heme oxygenases, glutathione transferases, heat-shock proteins, acute-phase proteins (Tchounwou et al., 2012b).

According to the United States National Toxicology Program and the International Agency for Research on Cancer, there is enough evidence to conclude that cadmium is a human carcinogen (Tchounwou et al., 2012b). It is believed that occupational exposure to cadmium increases the risk of developing lung cancer, and there is substantial evidence from rodent studies that the pulmonary system is a target organ for this designation as a human carcinogen (Tchounwou et al., 2012b). As a result, cadmium-induced human carcinogenesis is most clearly established in the lung (Tchounwou et al., 2012b). Animal cadmium carcinogenesis in addition to injection sites also affects the adrenals, testes, and hemopoietic system (IARC, 1993).

The US Environmental Protection Agency (US EPA) states that children are not anticipated to be negatively impacted by cadmium exposure in drinking water at a concentration of 0.04 mg/L for up to 10 days (Faroon et al., 2013). The US EPA states that exposure to 0.005 mg/L cadmium in drinking water over the course of a lifetime is not anticipated to have any negative consequences (Faroon et al., 2013). According to the American Food and Drug Administration, bottled water may contain no more cadmium than 0.005 mg/L. (Faroon et al., 2013). A legal limit of 5 g/m<sup>3</sup> of cadmium in the air, averaged over an 8-hour workday, was established by the Occupational Safety and Health Administration (OSHA) of the United States (Faroon et al., 2013).

#### 2.5.4 Mercury (Hg)

Mercury is a heavy metal that may be found in the periodic table's transition element series (Tchounwou et al., 2012b). Typically, mercury is recovered as a by-product of mining processing (L. A. Smith et al., 1995). The main source of mercury is the sulphide mineral cinnabar (Evanko & Dzombak, 1997). The three main forms of mercury are metallic elements, inorganic salts, and organic molecules, each of which has a different level of toxicity and bioavailability (Jaishankar et al., 2014). Mercury is frequently found in the forms of mercuric ( $\text{Hg}^{2+}$ ), mercurous ( $\text{Hg}_2^{2+}$ ), elemental ( $\text{Hg}_0$ ), or alkylated (methyl/ethyl mercury) compounds after being discharged into the environment (Evanko & Dzombak, 1997). The organic component of mercury found in the environment that is most frequently encountered is methylmercury (Dopp et al., 2004). Microorganisms in soil and water methylate inorganic (mercuric) forms of mercury to produce it (Dopp et al., 2004).

The manufacturing of chloralkali, the burning of garbage, and other industrial processes all release some elemental mercury into the environment as a result of anthropogenic emissions (FAO/WHO, 2011). Natural occurrences such as volcanoes also release some elemental mercury into the atmosphere (FAO/WHO, 2011). Mercury is the deadliest heavy metal, and there is no recognized physiological function for it in human metabolism (Salonen et al., 1995). The human body lacks any systems for actively excreting mercury (Salonen et al., 1995). Acute heavy metal poisoning is frequently brought on by the toxicity of mercury (Jaishankar et al., 2014). Mercury is a prevalent environmental toxin and pollutant that causes serious changes in human tissues and has a number of detrimental impacts on health (Bhan & Sarkar, 2005; Ogabiela et al., 2011).

Mercury may cause damage to any organ, as well as problems with the neurological system, muscles, and kidneys (Jaishankar et al., 2014). Both membrane potential and intracellular calcium

homeostasis may be affected (Jaishankar et al., 2014). Mercury vapours can cause bronchitis, asthma, and other acute respiratory illnesses (Jaishankar et al., 2014; Ogabiela et al., 2011). By adhering to selenohydril and sulfhydryl groups, mercury affects tertiary and quaternary protein structure and changes cellular function, which in turn causes methyl mercury to disturb cellular structure (Jaishankar et al., 2014; Patrick, 2002).

### **2.5.5 Copper (Cu)**

It is a naturally occurring reddish metal that is also present in small amounts in air, water, sediment, and rock (ATSDR, 2004). Many plants and animals also contain copper (ATSDR, 2004). The formation of hemoglobin, the metabolism of carbohydrates, the synthesis of catecholamines, and the cross-linking of collagen, elastin, and hair keratin all depend on the nutrient copper, which is essential at low intake levels (Tchounwou et al., 2008). Copper is a crucial element in many catalytic processes due to its capacity to collect or donate electrons (Harvey & Mcardle, 2008). The reduction of molecular oxygen is carried out by enzymes that require copper (Tchounwou et al., 2008). Some examples of these enzymes include monoamine oxidase, ferroxidases, superoxide dismutase, cytochrome C oxidase, and dopamine -monooxygenase (Tchounwou et al., 2008). Cuproenzymes use copper's capacity to cycle between an oxidized state, Cu(II), and a reduced state, Cu(I), in redox reactions (Tchounwou et al., 2008).

Despite this, copper has the potential to be dangerous due to the production of superoxide and hydroxyl radicals as a result of transitions between Cu(II) and Cu(I) (Camakaris et al., 1999). Micronutrient copper is important for the development of both plants and animals. It facilitates the human body's ability to produce blood hemoglobin (Wuana & Okieimen, 2011). In plants, it is crucial for water control, disease resistance, and seed production (Wuana & Okieimen, 2011).

Although copper is essential, when ingested in excess, copper poisoning can take both acute and long-term forms (ATSDR, 2004; Onakpa et al., 2018). Recently, a 0.9 mg daily (0.013 mg/kg daily) recommended dietary allowance (RDA) was created (Tchounwou, Yedjou, et al., 2003). Mining for copper and other metals, as well as establishments that produce or utilize copper metal or copper compounds, can leak copper into the environment (ATSDR, 2004). Dump sites, home wastewater, the burning of fossil fuels and trash, the manufacture of wood, and the creation of phosphate fertilizer are other ways that copper may enter the environment (ATSDR, 2004).

Additionally, it can infiltrate the environment naturally through wind-borne dust, native soils, volcanoes, decomposing plants, forest fires, and sea spray (ATSDR, 2004). Copper is hence widely distributed in the environment (ATSDR, 2004).

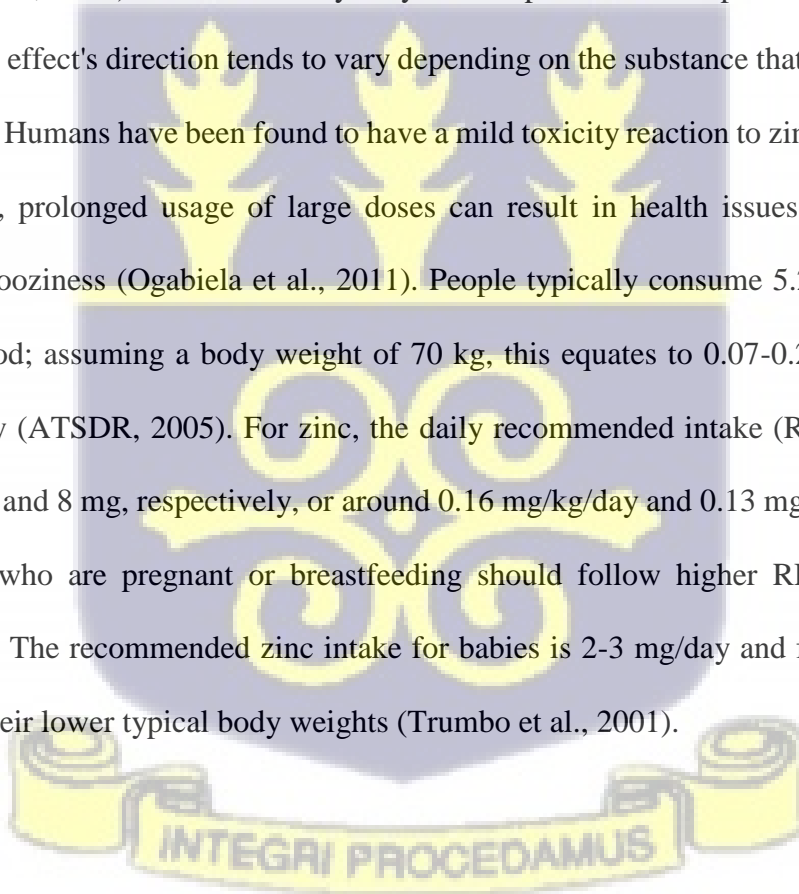
### **2.5.6 Zinc (Zn)**

In nature, zinc is abundant and contributes 20–200 ppm (by weight) of the Earth's crust (ATSDR, 2005). It does not present in nature as elemental zinc, but rather as zinc oxide or sphalerite (ZnS) (ATSDR, 2005). Zinc is a frequent environmental contaminant that is present in large quantities in the aquatic environment (Ogabiela et al., 2011). Approximately 70 mg per kilogram of crustal rocks contain zinc, which is naturally present in soil although in low proportions (Wuana & Okieimen, 2011). By mining, smelting zinc, lead, and cadmium ores, producing steel, burning coal, and burning trash, zinc is discharged into the environment (ATSDR, 2005). Normally, background ambient air contains 1 g/m<sup>3</sup> of zinc (ATSDR, 2005). Zinc levels in surface water are typically 0.05 mg/L, although can occasionally reach 50 mg/L. (ATSDR, 2005).

The micronutrient zinc is essential for all living things (Kumar Sharma & Agrawal, 2004). It is a vital nutrient for humans, present in all tissues, and acts as a cofactor for more than 300 enzymes

(US EPA, 2005). Animals and humans both need zinc for prenatal and perinatal growth, protein synthesis, and DNA and RNA stabilization (Kumar Sharma & Agrawal, 2004). Several metalloenzymes, including alcohol dehydrogenase, alkaline phosphatase, carbonic anhydrase, leucine aminopeptidase, and superoxide dismutase, need it in order to function properly (ATSDR, 2005). Dermatitis, anorexia, growth retardation, inadequate wound healing, hypogonadism with reduced reproductive potential, compromised immunological function, and restricted cerebral function are only a few of the disorders connected to zinc deficiency (ATSDR, 2005).

Additionally, a lack of zinc in mothers has been related to a higher incidence of congenital defects in infants (ATSDR, 2005). Zinc deficiency may also impact other compounds' ability to cause cancer, albeit the effect's direction tends to vary depending on the substance that causes the cancer (ATSDR, 2005). Humans have been found to have a mild toxicity reaction to zinc (Ogabiela et al., 2011). However, prolonged usage of large doses can result in health issues like neutropenia, tiredness, and wooziness (Ogabiela et al., 2011). People typically consume 5.2-16.2 mg of zinc per day from food; assuming a body weight of 70 kg, this equates to 0.07-0.23 mg of zinc per kilogram per day (ATSDR, 2005). For zinc, the daily recommended intake (RDA) for men and women is 11 mg and 8 mg, respectively, or around 0.16 mg/kg/day and 0.13 mg/kg/day (ATSDR, 2005). Women who are pregnant or breastfeeding should follow higher RDAs (12 mg/day) (ATSDR, 2005). The recommended zinc intake for babies is 2-3 mg/day and for children is 5-9 mg/day due to their lower typical body weights (Trumbo et al., 2001).



## 2.6 Heavy metals in Rice

One of the main ways that people are exposed to heavy metals is through food (Hasan et al., 2022). Due to their extreme toxicity, arsenic, cadmium, lead, and mercury are some of the priority metals of public health concern (Tchounwou et al., 2012b). These dangerous heavy metals may migrate from polluted soil to rice at a certain rate (Hasan et al., 2022). Heavy metal dispersion into the environment raises concentrations in cultivated soil and water, making the food chain a critical source of toxic metal exposure (Datta et al., 2000). Plant-derived foods can easily absorb heavy metals from soil (Huang et al., 2016).

Also, irrigation with metal-contaminated water or wastewater can contribute to soil contamination (Hang et al., 2009). Furthermore, the increasing use of fertilizers, insecticides, or pesticides may be a source of toxic metals such as Arsenic, lead and cadmium agricultural soil and crops (Azmy & Kippler, 2020). The rice plant has been identified as one of the plants that absorb many toxic metals from soil, and it adds to human metal exposure across the globe (Williams et al., 2007b).

Metal exposure from rice is affected by several factors, including rice consumption rate, the geography (location rice came from), metal sources (where the rice is grown), soil and irrigation water criteria, and rice variety consumed (Azmy & Kippler, 2020). Because metal exposure varies with rice consumption, the more rice people eat, the more metals they may be exposed to (Al-Rmalli et al., 2012). Additionally, the continuous increase in the use of pesticides and insecticides, as well as the use of more lands, such as mines and industrial lands, to meet the world's ever-increasing demand for rice, increases the risk of metal contamination in rice (Feigin et al., 2012).

Even for commercial purposes, people occasionally use food adulterants, such as urea for whitening rice, particularly polished rice, which increases the concentration of Cd in rice and rice products (Hossain et al., 2008). Rice roots have a greater capacity than other crops to absorb toxic

metals from soils and water in paddy fields (Huang et al., 2016). Anaerobic soil conditions in paddy fields have been shown to result in increased mobilization of toxic metals, making them more bioavailable to rice (Morekian et al., 2013). Furthermore, soil pH is critical (Azmy & Kippler, 2020). Alkaline soil (high pH) contains less lead and other metals such as copper, posing a lower risk of uptake by plants (Tariq & Rashid, 2013). The greater the area devoid of surface water, the higher the concentration of cadmium in the cultivated grain (Azmy & Kippler, 2020).

In various marketplaces, "rice grains" and "rice-based goods" had extraordinarily high average levels of total arsenic, ranging from 0.14 to 0.17 mg/kg and having between 0.1 and 0.4 milligrams of inorganic arsenic per kilogram of dry mass, according to the EFSA review (EFSA, 2009). Uncooked rice contains between 0.1 and 0.4 milligrams of inorganic arsenic per kilogram of dry mass (EFSA, 2009; Hojsak et al., 2015; Williams et al., 2007). Compared to other cereals like wheat and barley, which have levels of arsenic that vary from 0.03 to 0.08 mg/kg, rice has significantly higher arsenic (Williams et al., 2007a). Rice includes varying amounts of arsenic based on its variety, place of production, and method of processing; brown rice has a greater arsenic content than white rice (Meharg & Rahman, 2003). Arsenic levels may also change as food is being prepared, with boiling water suggesting being particularly important. For instance, reducing the quantity of arsenic in rice by boiling it in pure water (Daz et al., 2004).

Cereals are the principal food type to expose people to cadmium because of their widespread consumption (FAO/WHO, 2011). The EFSA Panel on Contaminants in the Food Chain proposed a tolerable weekly intake of 2.5 g/kg body weight to ensure adequate protection for all consumers, a level that is nearly 40% lower than the FAO/WHO-approved tolerance level. The provisional tolerable monthly intake of 25 g/kg body weight was established by the Joint Food and Agriculture Organization of the United Nations and the World Health Organization Expert Committee on Food

Additives (CTA, 2011). Previous research has shown that rice can accumulate fairly high levels of MeHg (0.174 mg/kg), especially in those regions where mercury mining is active (Ogabiela et al., 2011). These metallic substances are thought to be systemic poisons that, depending on the exposure amount, might cause organ damage (Tchounwou et al., 2012).

Therefore, the presence of harmful heavy metals in food crops like rice may have an adverse effect on health (Hasan et al., 2022).

## **2.7 Risk Assessment**

A risk assessment process was created in order to figure out or estimate the threat to a certain target organism, system, or (sub)population following exposure to a particular substance. This process considers the intrinsic characteristics of the individual agent of concern as well as the characteristics of the particular target system, and it also involves the identification of concomitant uncertainties. (IPCS, 2004).

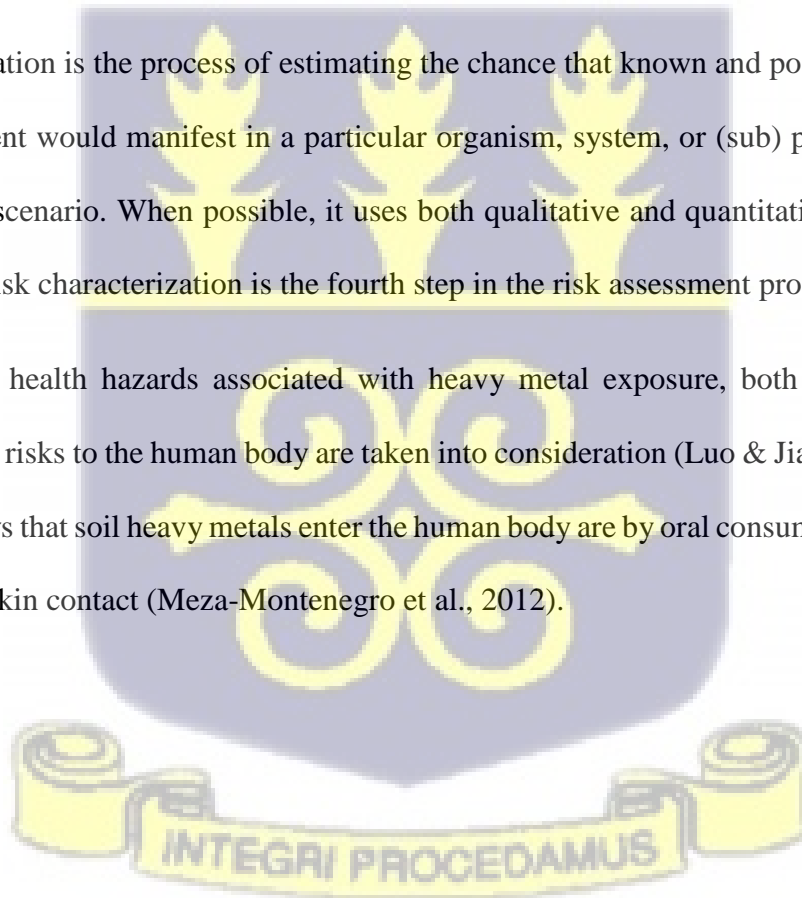
The risk assessment method comprises four stages: risk identification, dose-response assessment, exposure analysis and risk characterization. The process of assessing hazards begins with identifying potential hazards (IPCS, 2004). The dose is the quantity of the substance consumed by the exposed person (or given to the person) (Sheets, 2018). Biologically effective dose is the amount of the substance that reaches a target site where it would pose a hazard (Sheets, 2018).

The third phase of risk assessment is exposure assessment (IPCS, 2004). It is the most significant and vital component of risk assessment since it determines the actual level of human exposure to the food hazardous ingredient (de Oliveira et al., 2021). A wide range of estimations are produced depending on the type of consumer and eating habits, as well as the presence of acute or chronic intake, as each mycotoxin's exposure is defined by its concentration in the food and the amount

consumed (de Oliveira et al., 2021). Exposure evaluation measures how exposed an organism, system, or (sub) population is to a drug (and its derivatives) (IPCS, 2004). Concentration, exposure, dosage, and physiologically effective dose make up exposure assessment (Sheets, 2018). The concentration of a material indicates how much of it is present in the immediate area (Sheets, 2018). The material (heavy metals in this case) is typically found in air, water, soil, products, or transport or carrier media; the chemical concentration at the point of contact is the exposure concentration (US EPA, 1992). A time-dependent exposure concentration profile can be used to indicate exposure over a period (US EPA, 1992). Exposure is the term used to describe the degree of human contact with the chemical (Sheets, 2018; US EPA, 1992).

Risk characterisation is the process of estimating the chance that known and possible unfavorable effects of an agent would manifest in a particular organism, system, or (sub) population under a given exposure scenario. When possible, it uses both qualitative and quantitative methodologies (IPCS, 2004). Risk characterization is the fourth step in the risk assessment process.

To estimate the health hazards associated with heavy metal exposure, both carcinogenic and noncarcinogenic risks to the human body are taken into consideration (Luo & Jia, 2021). The three most typical ways that soil heavy metals enter the human body are by oral consumption, respiratory inhalation, and skin contact (Meza-Montenegro et al., 2012).



## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1 Study Design

This study comprised of a consumer survey and laboratory analyses. The survey was conducted to obtain information on consumption patterns (frequency and amount consumed) of locally produced rice and the laboratory analyses was to determine the levels of heavy metals in the various rice samples.

#### 3.2 Overview of Rice Consumption Survey

This research was conducted in the Accra Metropolis in the Greater Accra Region. A survey was conducted on local rice consumption. It involved the random selection of participants who were consumers of local rice and live in Accra Metropolis. Vulnerable participants who included infants and children were included but not interacted with directly. Questions involving such group were answered by parents or guardians. Questionnaires were issued in google forms via email and other social media platforms. Hard copies were also made available for participants without access to such online platforms. In all participant were made to sign a consent form before they were allowed to participate in the survey. The questionnaire was in a form of multiple choice and closed-ended questions. Some information gathered included:

- I. Amount consumed per meal (g/meal).
- II. Frequency of rice consumption (meals/week).
- III. Major point of purchase.
- IV. Personal Information (sex, age, body weight).

### 3.2.1 Sample Size Determination for Consumer Survey

The study adopted Cochran (1963) to calculate the sample size. Sample size was determined as:

$$n = \frac{Z^2 pq}{e^2} = \frac{1.96^2(0.5)(0.5)}{0.05^2} = \frac{0.9604}{0.0025} = 384.16 \approx 385$$

Where p is the percentage of people who consume rice, q = (1-p), e is the margin of error, and n is the projected minimum sample size. Z is the standard deviation of 1.96 at 95% confidence range.

The value for Z may be found in the statistical table that provides the area under the normal curve.

People who don't eat local rice were not included.

### 3.2.2 Ethical approval

The protocol for this study was submitted to the Ethics Committee for Basic and Applied Sciences (ECBAS) for approval. The study was conducted after approval is granted from the ECBAS with approval reference number ECBAS 033/21-22.

### 3.3.1 Sampling of Rice for Estimation of Heavy Metal content

Previous studies on local rice production in Ghana, consultation with local rice producers and market women revealed the Ghana local rice are categorised based on provenance. A convenient sampling approach was employed to collect samples of local rice from randomly chosen local retail markets in Accra Metropolis. The selected markets were Makola, Nima, Kaneshie, Agbogloloshie, and Madina. The rice samples were subjected to instrumental analysis to ascertain their Arsenic, Lead, Cadmium, Mercury, Copper, and Zinc levels. Some imported rice samples were also included to compare their level of the various heavy metals to the locally produced rice samples. In all forty (40) rice samples were obtained. Thirty (30) were locally produced rice and ten (10) were imported rice samples.

### **3.3.2 Estimation of Heavy Metals in Rice Samples**

#### **3.3.2.1 Reagents and Chemicals**

Ultra-pure water (deionised water) from Ghana Standards Authority, Nitric acid (65% v/v) from Fisher Scientific (Pennsylvania, USA), Reference multielement stock standard solutions (Pb, AS, Cu, Cd and Zn) and a single element reference standard solution of mercury (Hg) from Sigma Aldrich (Darmstadt, Germany), Hydrogen peroxide (30% v/v) solution and Blank Solution.

#### **3.3.2.2 Sample Pre-treatment**

A stainless-steel homogenizer was used to blend and homogenize the rice samples (Warring Commercial blender). To ascertain the varied levels of heavy metals, the samples were microwave digested and then subjected to an ICP-MS analysis. A powerful mixer grinder was used to crush the rice samples (Warring commercial blender). The materials were weighed using an electronic scale, and they were digested using an Italian microwave digester (Milestone start D Sorisole). The solution was stored for examination in centrifuge tubes (50mL).

#### **3.3.2.3 Digestion Procedure**

A Teflon PTFE jar was used to weigh each sample twice (0.5g each). One (1) mL of deionized water, 5 mL of HNO<sub>3</sub> (65% v/v), and 3 mL of H<sub>2</sub>O<sub>2</sub> (30% v/v) were used to treat the samples of powdered rice. Following that, the samples were digested in a microwave digester for 50 minutes at 170 °C, 50 bars of pressure, and 1000 watts of power. The digested samples were put into the 50 mL centrifuge tubes after they had cooled to room temperature and were topped off with 25 mL of deionized water.

### 3.3.2.4 Equipment for Heavy Metal Analysis

ICP-MS (Inductively Coupled Plasma - Mass Spectrometer): A NexION triple quad mass spectrometer that operates in the mass range of 5 amu to 20 amu and uses an inductively coupled argon (Purity of at least 99.99%) plasma. The mass spectrometer had a sensitivity to reach the analysis's detection limit and could resolve 1amu peak width at 5% peak height or better (resolution 300) when utilized in routine settings. It also had a nebulizing system, a low-pulsion peristaltic pump, and a mass flow controller for the nebulizer gas.

### 3.3.2.5 Quality Control and Assurance

To guarantee that the analytical data obtained is correct and dependable, quality assurance techniques were used during the study. Each set of samples had its own reagent blanks tested as a guide to ensure that sample findings were accurate in the case of heavy metal contamination in the water or reagents utilized. Additionally, each batch of analysis contained a verified reference material with predetermined concentrations (CRM Dorm 4, and FAPAS proficiency material). The certified reference materials (Dorm 4) and PT (powdered rice) used in this research were given by the National Research Council of Canada and FAPAS, in that order. To make sure the ICP-MS is being monitored and managed, standard solutions were checked periodically (1 in every 10 samples) throughout the studies. Samples were checked in duplicate to guarantee consistent test outcomes.



### 3.4 Exposure Risk Assessment

Exposure assessment and Human Risk for each metal was determined using the (U.S. EPA, 1989) approach as follows:

i) Daily intake assessment (EDI)

$$EDI = C \times IR \times ED \times EF/BW \times AT$$

The terms listed below are defined: C represents the concentration of various metals in rice (ng/g), IR represents the average daily consumption of rice (g/d), ED represents the exposure period (64.68 years, which is equal to the average lifespan in Ghana), EF represents the exposure frequency (365 days per year), BW represents the body weight (kg), and AT represents the average exposure time (U.S. EPA, 1989, 2020).

ii) Estimated Weekly Intake (EWI)

$$EWI = C \times WC/BW$$

where BW is the average body weight, WC is the weekly rice consumption for each person, and C is the average concentration of heavy metals in rice (mg/kg) (kg)

iii) Non-carcinogenic risks

The following equation, known as the Hazard Quotient (HQ), was used to calculate the non-carcinogenic risks: HQ is calculated as  $EDI / RfD$ , where RfD ( $mg\ kg^{-1}\ day^{-1}$ ) is the reference dosage of each heavy metal under research (Saha et al., 2016). A potential non-carcinogenic influence on human health would exist if the computed HQ value is greater than one. The non-carcinogenic impact is unlikely to occur if value is less than or equal to one.

#### iv) Carcinogenic Risks

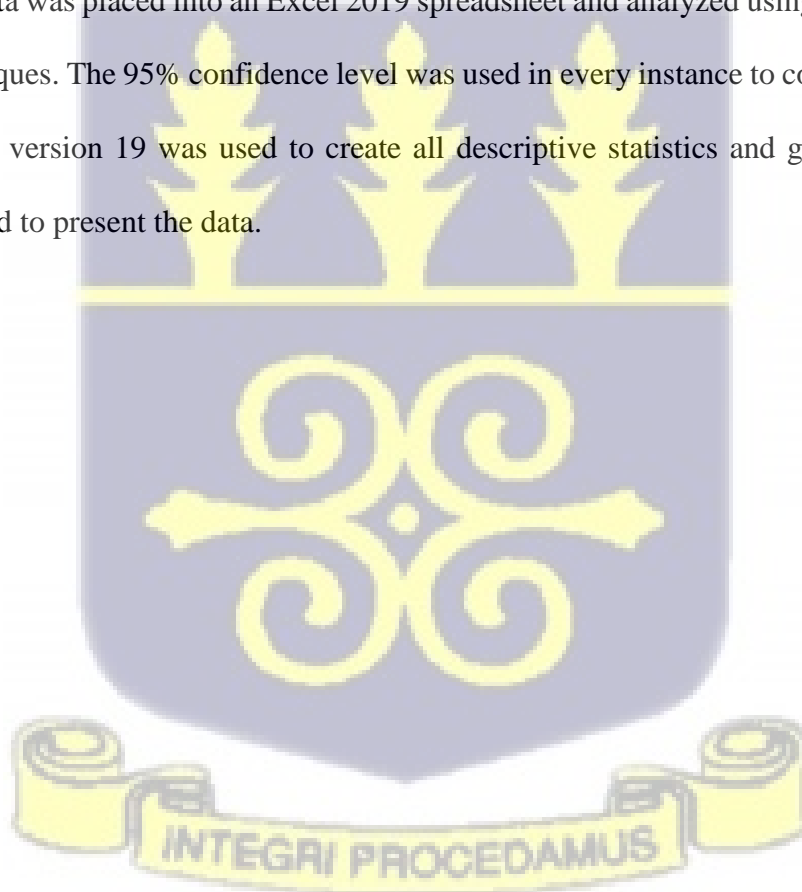
The carcinogenic risk is the possibility of developing cancer in a person's lifetime because of exposure to a probable carcinogen. The equation below was used to calculate the cancer risk

$$(\mathbf{CR}) = \mathbf{EDI} \times \mathbf{SF}$$

where: *EDI* (mg /kg/BW/day) is the estimated daily intake, *SF* (mg/kg/day) is the slope factor of the various metals (U.S. EPA, 1988).

### 3.5 Data Analysis

The collected data was placed into an Excel 2019 spreadsheet and analyzed using SPSS's ANOVA statistical techniques. The 95% confidence level was used in every instance to compare the means. Microsoft Excel version 19 was used to create all descriptive statistics and graphs. Tables and figures were used to present the data.



## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.1 Local Rice Varieties

Information acquired from the traders during the collection of rice samples for heavy metal analysis revealed that local rice is split into two categories: branded and unbranded. Most of the local rice types found in market areas were classified according to their source, or site of cultivation. The indigenous varieties of rice were Tamale brown rice, Tamale white rice, Hohoe brown rice, Hohoe white rice, Kumasi brown rice, and Kumasi white rice. This was an indication the local rice sold in Accra's market areas originates in the Hohoe area of the Volta Region, Kumasi of the Ashanti Region, and Tamale of the Northern Region.

#### 4.2 Survey on Local Rice Consumption

A total of 385 participants were consented to participate in the consumer survey. Personal information (sex, age, and body weight) and the amount of local rice consumed per meal (g/meal), frequency of rice consumption (meals/week), principal point of purchase, and consumption frequency were some of the data collected. Infants and young children were not directly interacted with as they were vulnerable participants. This group's questions were addressed by parents or guardians.



#### 4.2.1 Gender Distribution of Respondents

Three hundred and eight-five (385) respondents' gender breakdown is shown in Figure 1. Male respondents made up 164, or 43% of the participants, while female respondents made up 221 or 57% of the respondents. Female participants made up a larger percentage of respondents than male respondents, because when data were being collected, women were far more approachable and eager to interact than men, who typically provided excuses for their busyness or general unwillingness to listen to what you had to say.

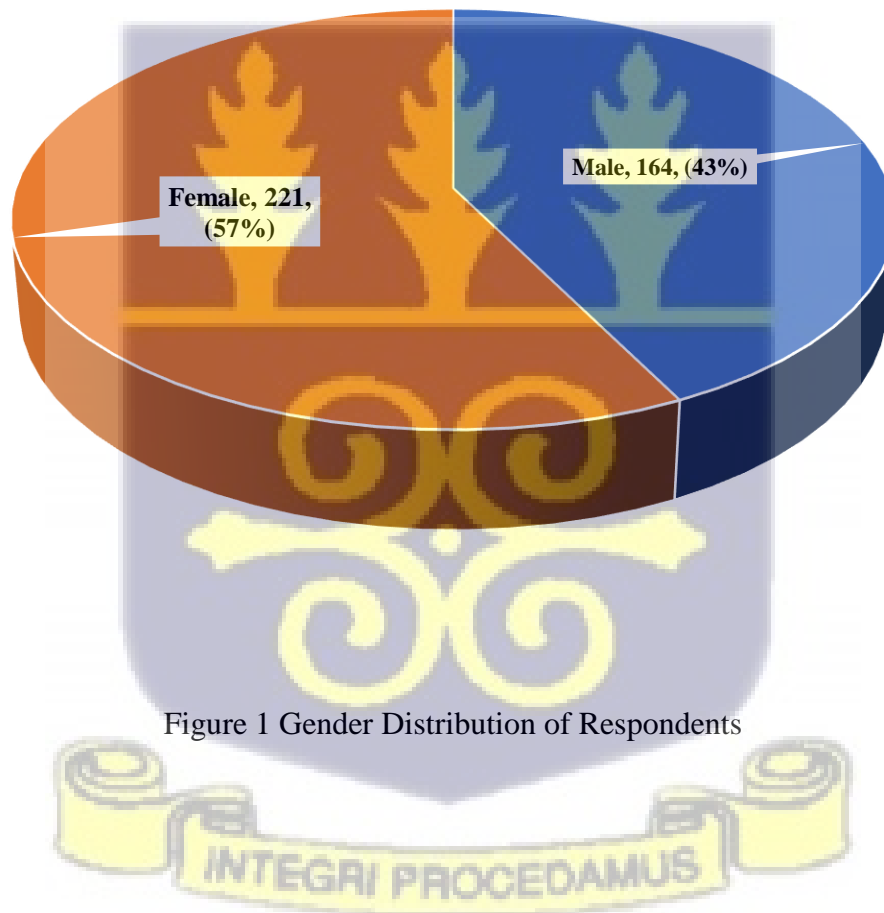
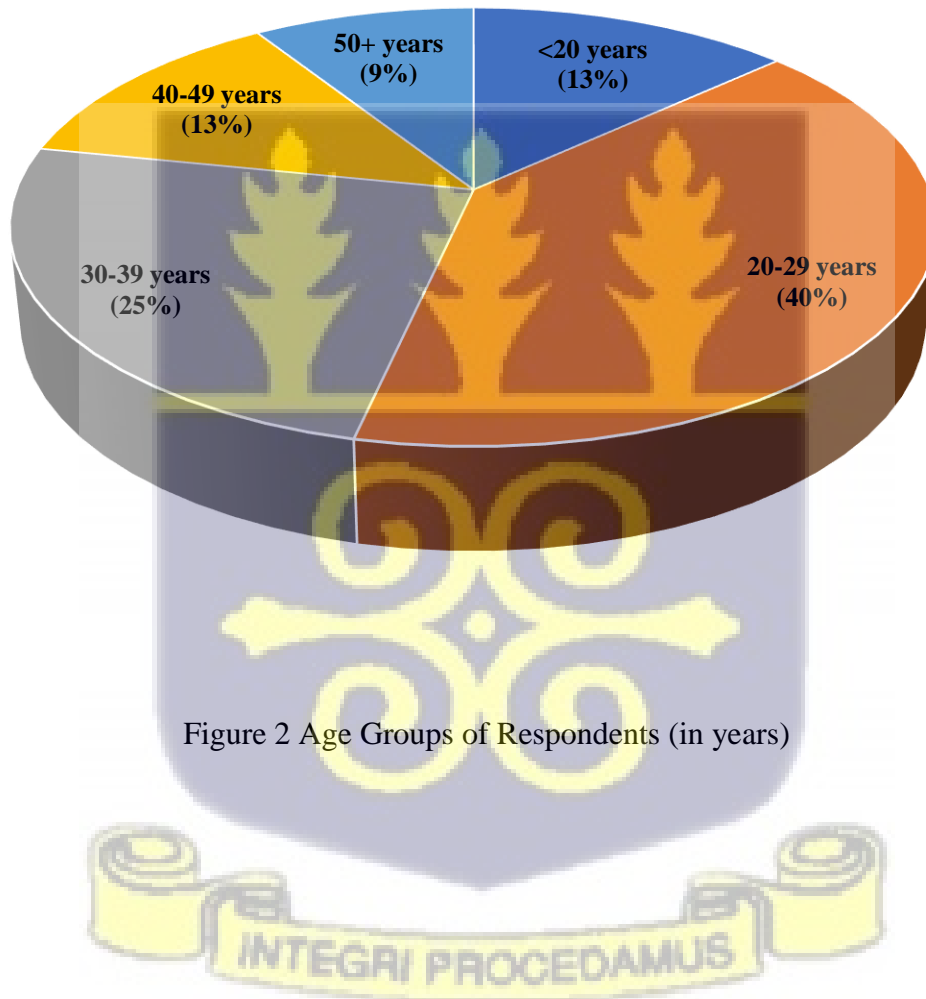


Figure 1 Gender Distribution of Respondents

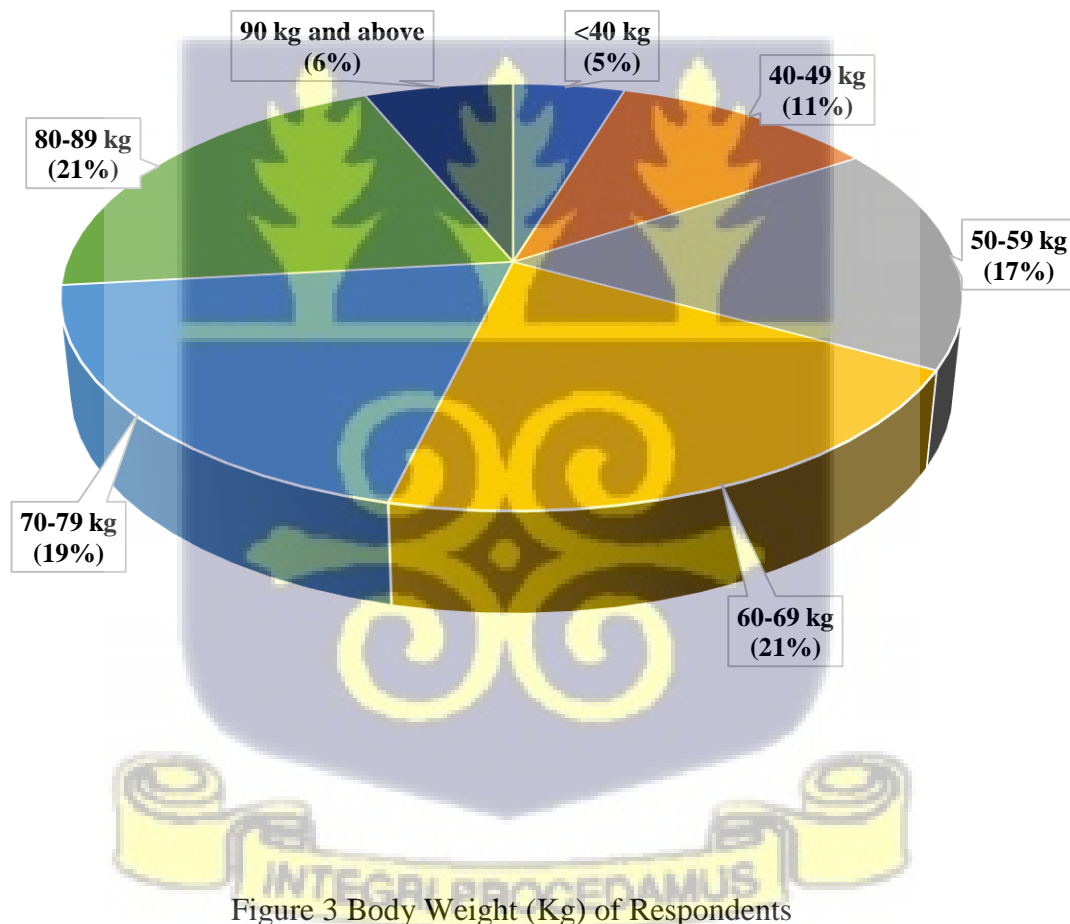
#### 4.2.2 Age Group of Respondents

In groups, Figure 2 displays the 385 respondents' age distribution. Fifty-one representing 13% of the 385 respondents were under the age of twenty. Twenty to twenty-nine (20–29)-year-olds made up 155 respondents (40%); 30–39-year-olds made up 95 (25%); 40–49-year-olds made up 49 (13%); and people over 50 made up 35 (9%).



### 4.2.3 Body Weight of Respondents

Figure 3 displays the respondents' body weights (in kg). Out of 385 responses, 18 were under 40 kg (>40 kg) in weight, 43 were in the (40-49) weight range, 66 were in the (50-59) weight range, 80 were in the (60-69) weight range, 75 were in the (70-79) weight range, 79 were in the (80-89) weight range, and 24 were 90 kg and more.



#### 4.2.4 Educational Level of Respondents

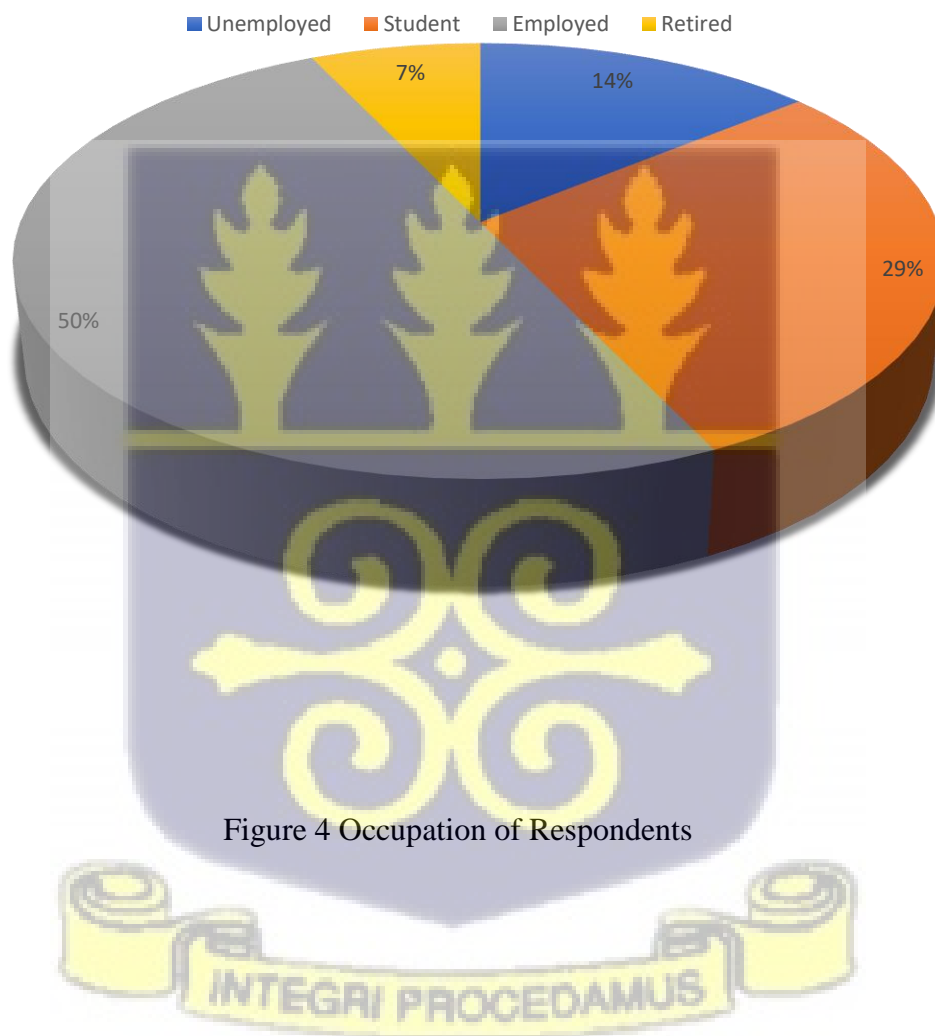
The respondents' highest level of education is shown in Table 1. Of the 385 responses, 12 cited primary school, 36 said they had finished middle school or junior high school, 93 said they had finished sixth form or secondary school, and 244 said they had completed postsecondary education. This implies that everyone who replied to the survey had some type of formal education, and that more than half had finished tertiary education. This made it easier to collect data because most people understood the concept and what was required of them. Additionally, there were comments and even suggestions on how to strengthen the nation's domestic rice industry because most respondents were aware of how most neighbouring nations—Nigeria, for instance—produce and consume domestically grown rice as opposed to imported foreign samples.

Table 1 Educational Level of Respondents

Highest Educational Level	Frequency (N)	Percentage (%)
Primary school	12	3
Middle School/JHS	36	9.4
Sixth Form/Secondary School	93	24.2
Tertiary	244	63.4
None	0	0
Total	385	100

#### 4.2.5 Occupation of Respondents

The respondents' occupations are displayed in Figure 4. Out of 385 respondents, 50% were employed; 29% were students; 14% were unemployed; and 7% were retired. With less than 30% being either unemployed or retirees, this shows that more than 70% of the respondents were either employed or students.



#### 4.2.6 Reasons for the Consumption of Local Rice

Figure 5 displays the justifications given by respondents for eating local rice. Ten (10) of the 385 respondents said price, 12 mentioned packaging, 18 preferred quality, 30 mentioned taste, 60 selected closeness to the point of purchase, 60 mentioned aroma, 65 mentioned cooking ease, and 130 mentioned nutritional content as being reasons for consuming locally produced rice. This outcome shows that most respondents consume it for its nutritional value. Additionally, after speaking with the majority of respondents, some came to the conclusion that most of our locally produced foods are free of added additives and chemicals, making them natural and healthy for their bodies' development as opposed to imported samples, which are high in chemicals.



Figure 5 Reasons for Consuming Local Rice

#### 4.2.7 Place of Purchase for Local Rice

Where respondents bought their local rice is shown in Table 2. Two hundred out of the 385 respondents purchase their local rice from the neighbourhood open market, 68 mentioned a grocery store, convenience store, or shopping centre, and 117 identified a restaurant or fast-food joint as the various points where they purchase their local rice. Due to pricing, the majority of respondents said that their preferred place to make a purchase was not a supermarket, convenience store, or shopping mall. This is because most of these establishments stock branded samples that are slightly more expensive than what is offered in local open markets.

Table 2 Place of Purchase for Local Rice

Place of Purchase	Frequency (N)	Percentage (%)
Local open market	200	52
Supermarket/shopping mall	68	18
Restaurant or food joints	117	30
Total	385	100



#### 4.2.8 Local Rice Consumption by Respondents

Figure 6 displays the respondents' local rice consumption habits. Ninety (90) people indicated that local rice is a staple in their diet; 220 of them consume it weekly, 60 consume it monthly, and 15 consume it annually. This demonstrates that rice is a common staple food. This is consistent with a Ministry of Food and Agriculture assessment from 2020 that named rice as the second-most significant cereal after corn and that it has established itself as a significant staple food in Ghana. (MoFA, 2020).

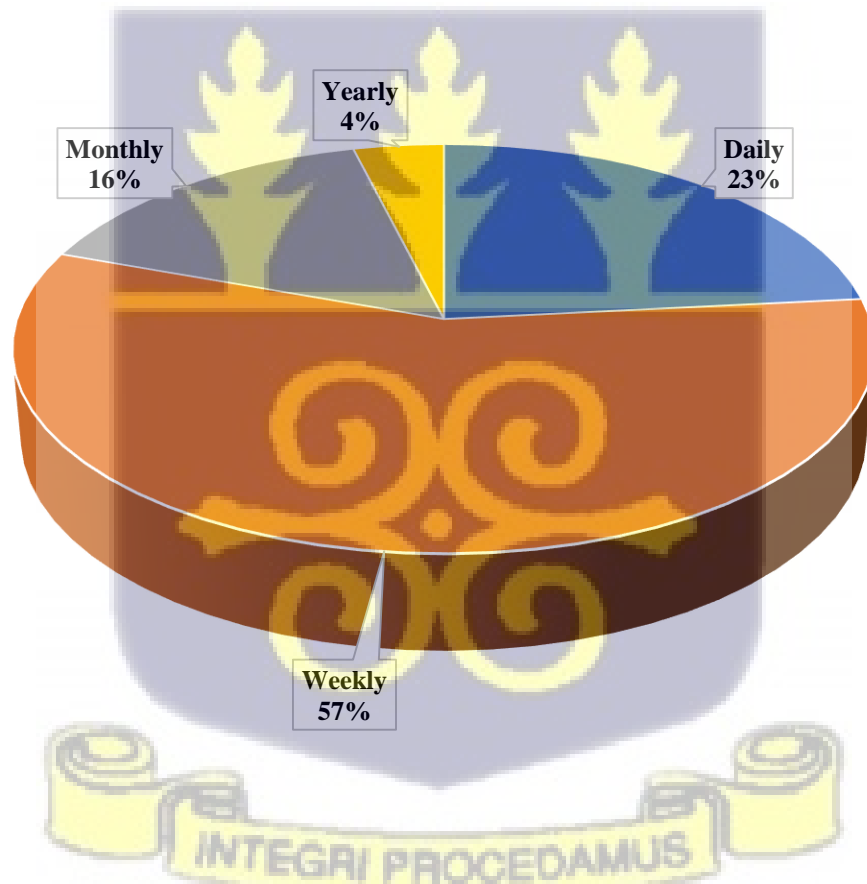


Figure 6 Local Rice Consumption Pattern of Respondents

#### 4.2.9 Frequency and Quantity of Local Rice consumption for Adults

The amount of local rice consumed by respondents and their associated patterns were described in Table 3. Forty-two respondents consumed 175 grams of local rice per day, 48 consumed 262.5 grams per day, 12 consumed 262.5 grams once per week, 8 consumed 350 grams once per week, 10 consumed 437.5 grams per week, 35 consumed 525 grams per week, and 155 consumed more than 525 grams per week, 60 consumed more than 525 grams once per month, and 15 consumed more than 525 grams once per year. It is clear from the data that more respondents consumed rice on a daily and weekly basis than on a monthly and yearly basis.

Table 3 Quantity and Frequency of Local Rice Consumption for Adults

Quantity consumed (grams)	Pattern	Frequency	Percentage (%)
175	Daily	42	10.9
262.5	Daily	48	12.5
262.5	Weekly	12	3.1
350	Weekly	8	2.1
437.5	Weekly	10	2.5
525	Weekly	35	9.1
525+	Weekly	155	40.3
525+	Monthly	60	15.6
525+	Yearly	15	3.9
Total		385	100

#### 4.2.10 Consumption of Local rice by Children

##### 4.2.10.1 Respondents whose households had children who consume Local Rice

Children who eat local rice in their households are represented in Figure 7. Two hundred and twenty-six of the 385 respondents have children who eat local rice at home, as opposed to 159 who do not.

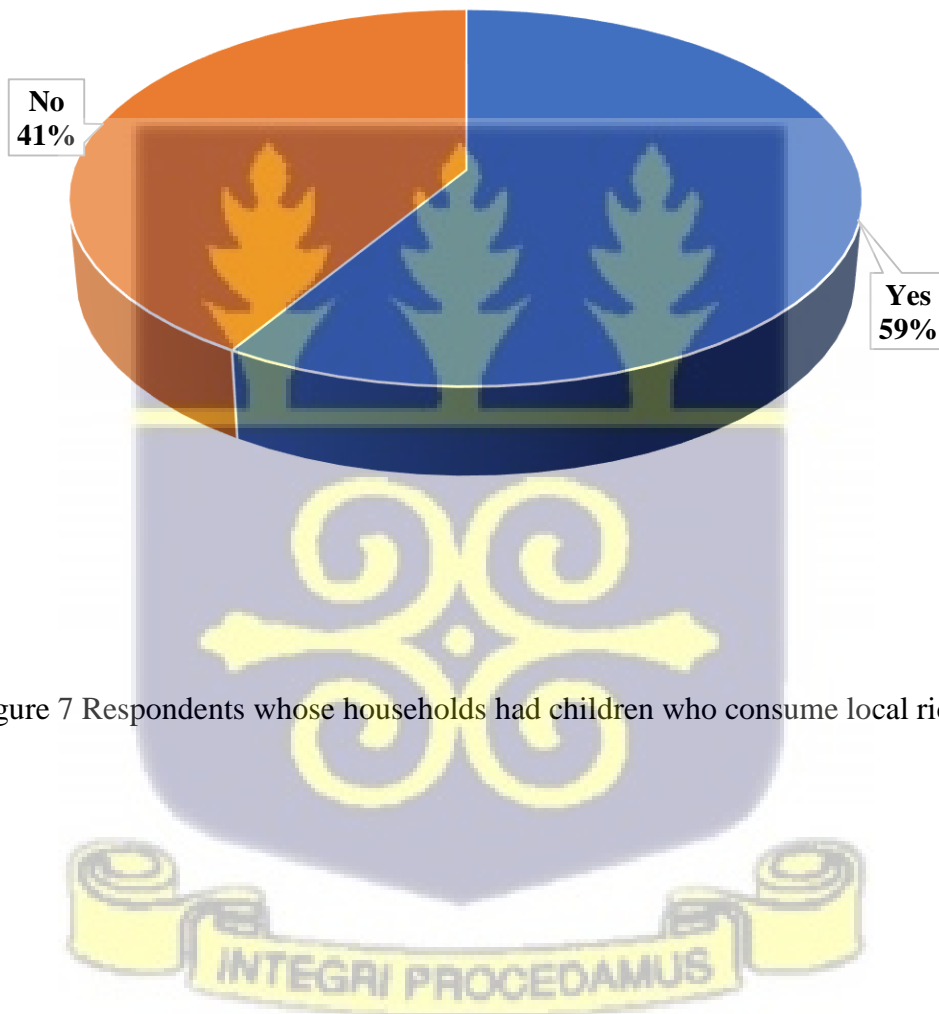


Figure 7 Respondents whose households had children who consume local rice

#### 4.2.10.2 Age group distribution of children in respondents' households

The distribution of children's ages in the households of respondents is shown in Figure 8. There was a total of 405 children. Forty-five children were identified in the age ranges of 6 to 11 months, 120 in 1 to 3 years, 140 in 4 to 9 years, and 100 in 10 to 14 years.

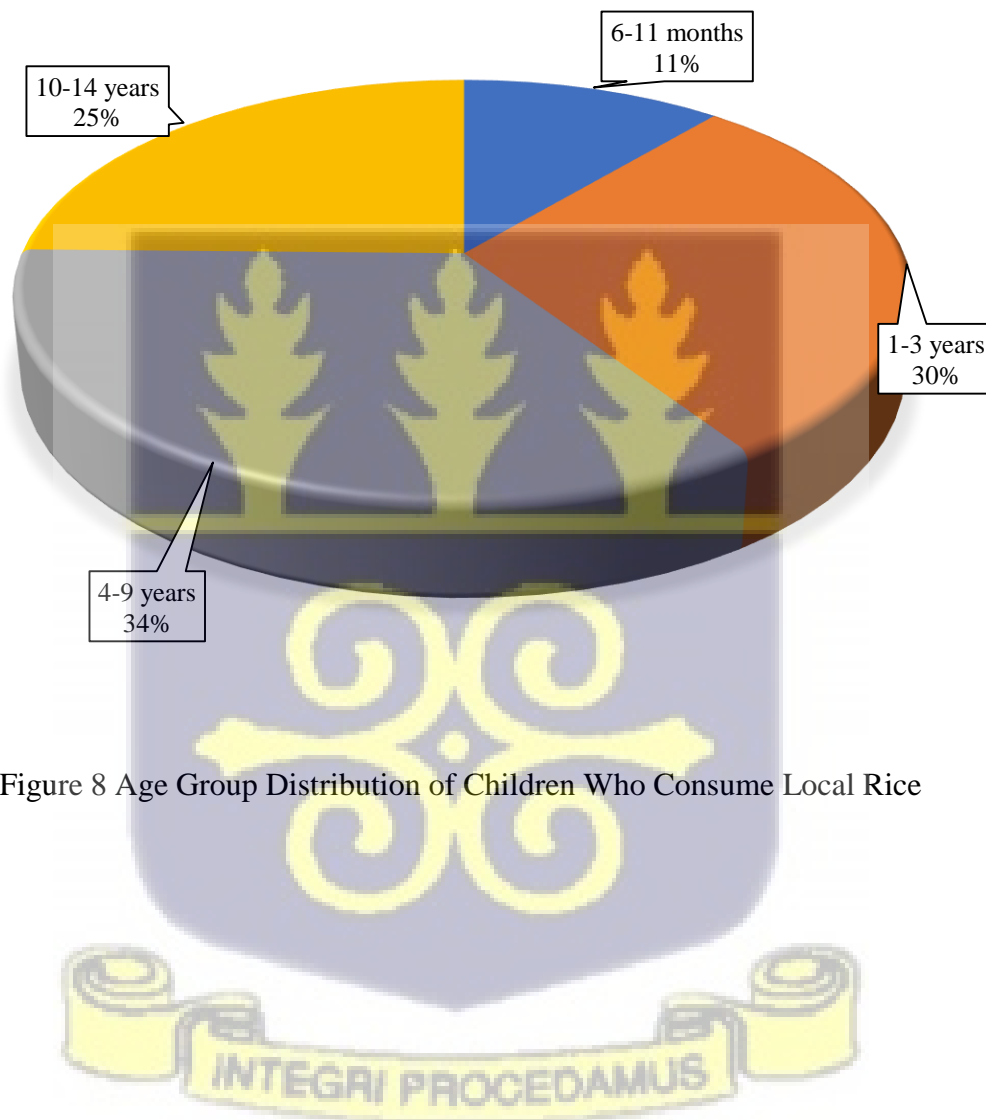


Figure 8 Age Group Distribution of Children Who Consume Local Rice

#### 4.2.10.3 Body weight of children who consume Local Rice

The weight distribution of 405 children in the household of the respondents are shown in Figure 9. Eighteen children were under 5 kilograms in weight, 43 were between 5 and 10 kilograms, 90 were between 11 and 20 kilograms, 75 were between 21- 30 kilograms, 76 were between 31 and 40 kilograms, 79 were between 41 and 50 kilograms, and 24 were over this weight (50 kilograms).

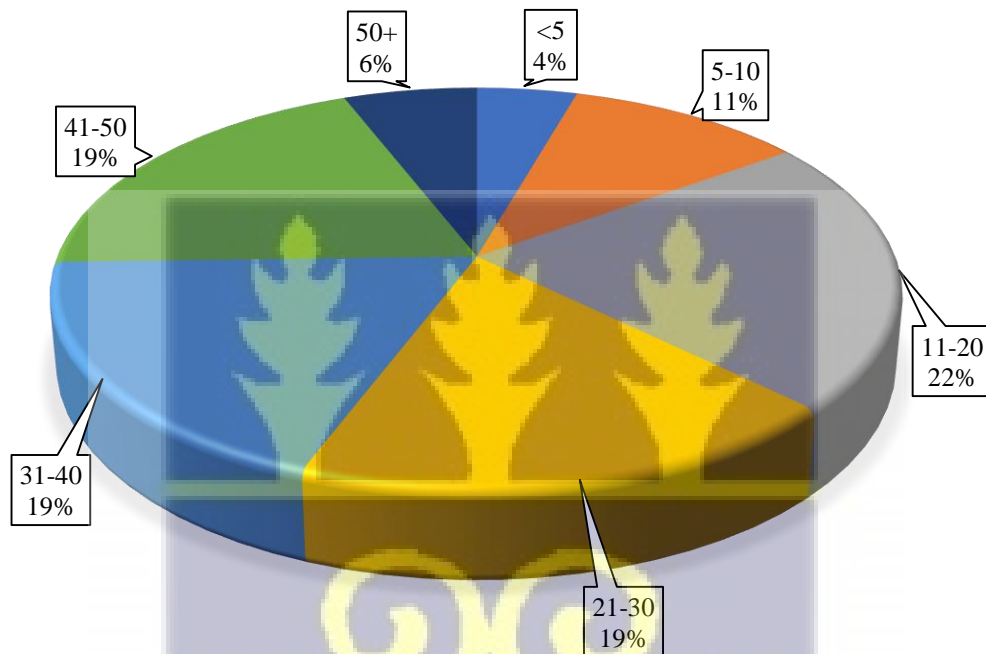
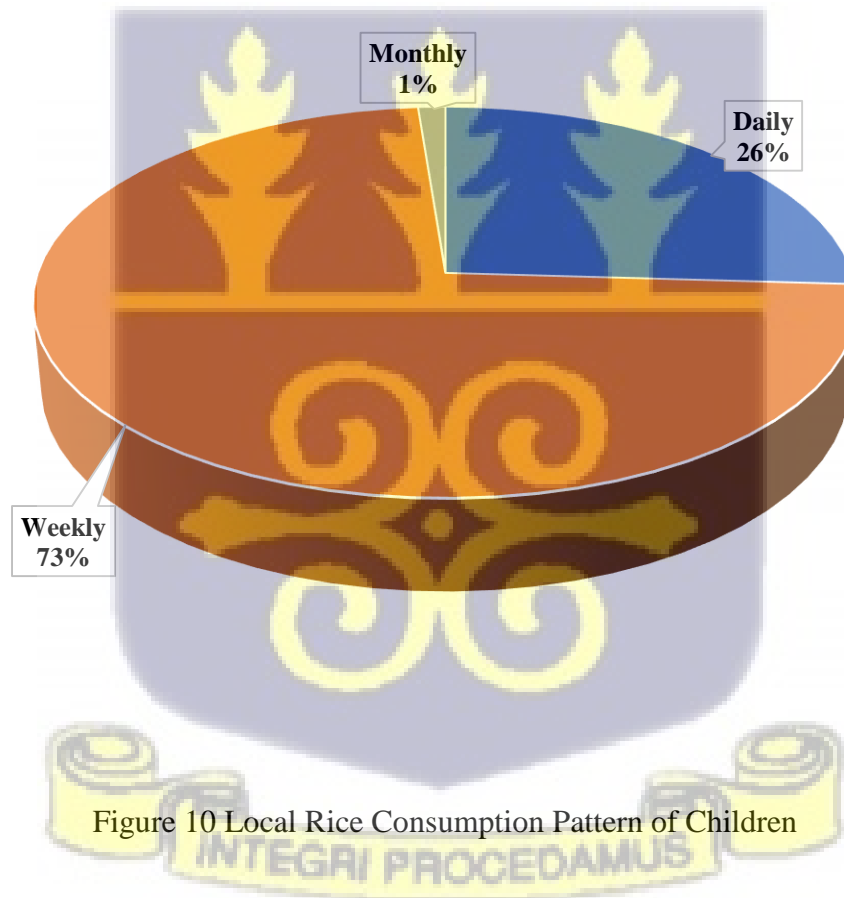


Figure 9 Body Weight of Children who Consume Local Rice



#### 4.2.10.4 Local Rice Consumption pattern of Children

The local rice consumption pattern of 405 children is displayed in Figure 10. Of the 405 kids, 105 ate local rice every day, 295 ate it once a week, and 5 ate it once a month. Only 5 children ate local rice every month, which means 99% of children ate local rice every day and every week. Adult consumption patterns were more prevalent on a daily and weekly basis. Therefore, children's local rice consumption habits mirrored those of adults. This may be mostly due to the fact that most parents and other adult caregivers have a significant impact on the amount, caliber, and eating habits of their children. (Robinson et al., 2001; Scaglioni et al., 2008).

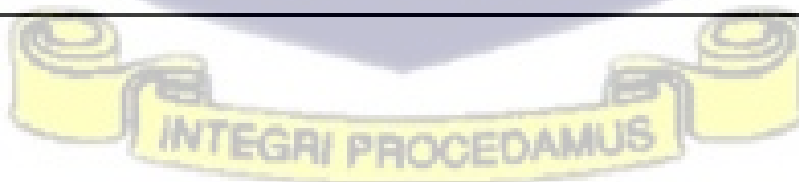


#### 4.2.10.5 Quantity and Frequency of Local Rice Consumption by children

The quantity and frequency of local rice eating among 405 kids are shown in Table 4. From the 405 kids, 70 ingested 34.75 grams every day, 35 consumed 87.5 grams every day, 83 took 87.5 grams every week, 140 consumed 175 grams every week, 70 consumed 262.5 grams every week, and 5 consumed 350 grams every month. Similar to adults, more children ate rice daily, weekly, and occasionally.

Table 4 Quantity and Frequency of Local Rice Consumption by Children

Quantity consumed (grams)	Pattern	Frequency	Percentage (%)
43.75	Daily	70	17.3
87.5	Daily	35	8.6
87.5	Weekly	83	20.5
175	Weekly	140	34.6
262.5	Weekly	70	17.3
350	Weekly	2	0.5
350	Monthly	5	1.2
Total		405	100



The average weight and age for both children and adults are shown in Table 5. Additionally, it shows the typical daily and weekly intake for both adults and kids.

Table 5 Average (age group, weight, and quantity of rice consumed) by children and adults

	Average age group (years)	Average weight (kilograms)	Average daily intake (grams)	Average weekly intake (grams)
Adult	20-29	60-69	221.67	496.36
Children	4-9	21-30	58.33	142.43



#### 4.3.1 Heavy Metals Analysis of Local Rice Samples

To determine the concentrations of arsenic, lead, cadmium, mercury, copper, and zinc, local rice samples were procured from open retail markets in the Accra Metropolitan Area. This study used six (6) different types of locally grown rice. Thirty (30) samples of locally produced rice were collected from the Nima, Kaneshie, Madina, Markola, and Agboghloshie markets, which are among the five (5) largest local open markets in the Accra Metropolitan Area. VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White) are the names given to the local rice samples based on their provenance where they are cultivated or produced. The same process utilized for the local rice analysis was applied to ten (10) additional foreign rice samples to compare the different heavy metal contents in them.

#### 4.3.2 Arsenic (As)

The maximum and minimum concentrations of Arsenic found in the 30 rice samples was 0.123 mg/kg and 0.0082 mg/kg which was found in two different Volta Brown samples. The mean concentration of Arsenic in Volta Brown was 0.05 mg/kg, Volta White was 0.038 mg/kg, Ashanti Brown was 0.06 mg/kg, Ashanti White was 0.056 mg/kg, Northern Brown was 0.056 mg/kg, Northern White was 0.044 mg/kg, presented in table 6. One-way ANOVA analysis displayed no significant variations ( $p > 0.05$ ) in the mean concentrations (Table 6).

The amount of arsenic discovered in the local rice samples was less than the maximum permitted limit allowed by Codex (0.2 mg/kg). While both local and imported rice are below the Codex maximum allowable values, the mean concentration for the ten imported rice samples that were

examined was 0.081 mg/kg, suggesting that the amount of arsenic in imported rice was greater than local rice.

A study conducted by Asamoah, (2016), also found concentrations of Arsenic in the unpolished and polished rice samples to be lower than the CODEX allowed limits for rice. Adomako et al. (2021) also found a lower concentration of Arsenic in Ghanaian rice as compared to other countries such as the United States and Thailand. Studies from other nations discovered higher levels of arsenic in samples of rice. For instance, rice grains from the south and east of China's Hunan Province have significant amounts of total arsenic, according to Ma, Wang, Jia, and Yang's (2016) research. In two high-yielding rice cultivars produced in paddy fields in Matlab, Bangladesh, Sandhi et al., (2017) also discovered higher concentrations of arsenic (0.09-0.21 mg As kg<sup>-1</sup>). Arsenic was identified in rice samples that were analyzed at a higher concentration than other metals. This supports research by Adomako et al. (2011), who found that Ghanaian rice had a greater arsenic content than other grains.

However, compared to global mean values, Ghanaian rice has lower Arsenic values according to Adomako et al., (2011), which has been confirmed in this study. Although arsenic naturally occurs in the ground, its concentration in soils has grown because of its usage in irrigation water and various mobilization processes, ATSDR (2007). This has had an impact on the agricultural system and led to arsenic absorption in rice (Kalita et al., 2018). In addition, compared to other heavy metals, rice has a greater translocation factor (TF) for arsenic (0.8), which might explain why there is a larger concentration of arsenic in the rice samples. Arsenic is considered as one of the elements with a high risk of soil to food chain transfer (Zhao & Wang, 2019). Rice grown amid continual floods has a large amount of arsenic in its edible component, claim Meharg and Rahman (2003). This is because iron oxyhydroxide plaque develops, releasing a considerable amount of arsenic

into the plant. Iron oxyhydroxide plague develops because of the oxygenation of the plant's rhizosphere in anaerobic environments, and the rate at which the plague forms rise in low phosphorus environments. A phosphate co-transporter also transports arsenic from the plant's roots to the grains (Meharg & Rahman, 2003).

Table 6 Arsenic (As) content of local rice samples

Heavy Metal	Rice Sample	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)
Arsenic	VB	0.0082	0.1233	0.0503±0.0525
	VW	0.0202	0.0573	0.0384±0.0016
	AB	0.0428	0.0719	0.0602±0.0124
	AW	0.0134	0.0867	0.0412±0.0285
	NB	0.0088	0.1043	0.0557±0.0401
	NW	0.0251	0.0616	0.0440±0.0134

No significant variations between means ( $p>0.05$ ) No. of samples = 30, Codex standards (0.2 mg/kg). VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White).

Table 7 Arsenic (As) Content of foreign rice samples

Heavy Metal	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Arsenic	0.0810	0.0510	0.1130
Number of samples =10			



#### 4.3.3 Lead (Pb)

There were no detectable levels of lead in 27 local rice samples, except Ashanti White, Volta Brown, and Northern Brown. Highest concentration of lead was 0.498 mg/kg found in Northern Brown rice. Volta Brown, Ashanti White, and Northern Brown all had mean lead concentrations of 0.004 mg/kg, 0.011 mg/kg, and 0.0996 mg/kg, respectively. No significant variation ( $p > 0.05$ ) in the mean concentrations was observed (table 8). Meanwhile, there was no concentration of Lead in 9 imported rice samples analysed, except one sample with a concentration of 0.0197 mg/kg. Lead concentration of (0.498 mg/kg) discovered in one of the local rice samples was significantly higher than the Codex maximum allowed value of (0.2 mg/kg).

Research conducted by Asamoah, (2016) also found concentrations of Lead in the unpolished and polished rice samples to be lower than the CODEX allowed limits for rice. Adomako et al. (2021) also found a lower concentration of Lead in Ghanaian rice as compared to other countries such as the United States, and Thailand. In a comprehensive examination of rice grains from marketplaces in 13 countries, including Ghana, Norton and his associates examined 1578 samples in total for Lead. None of the rice samples from Ghana surpassed the 0.2 mg/kg EU permitted limits, even though 0.6% of the samples surpassed that allowable limit (Norton et al., 2014).

On the contrary, studies conducted elsewhere found higher concentrations of Lead in rice samples analysed. For example, Yang et al. (2004) found higher concentration of Lead in rice samples analysed in the Lechang of Guangdong Province, South China (Yang et al., 2004). Studies have identified that rice can become enriched with Lead more than the allowable limits (Flora et al., 2007; Norton et al., 2014; Yang et al., 2004) which could be because of human activities such as fossil fuel combustion, mining, and manufacturing (Martin & Griswold, 2009; Tchounwou et al., 2012b).

Table 8 Lead (Pb) content of local rice samples

Heavy Metal	Rice Sample	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)
Lead	VB	0.0000	0.0184	0.0037±0.0037
	VW	0.0000	0.0000	0.0000
	AB	0.0000	0.0000	0.0000
	AW	0.0000	0.1382	0.0277±0.0276
	NB	0.0000	0.4979	0.0996±0.0996
	NW	0.0000	0.0000	0.0000

No significant variations between means ( $p > 0.05$ ) No. of samples = 30, Codex standards (0.2 mg/kg). VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)

Table 9 Lead (Pb) Content of foreign rice samples

Heavy Metal	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Lead	0.0091	0	0.0197

Number of samples =10



#### 4.3.4 Cadmium (Cd)

There were traces of Cadmium found in all except six (6) local rice samples analysed. The maximum concentration of Cadmium in the rice samples was 0.042 mg/kg, found in Ashanti Brown. The mean concentration of Cadmium in Volta Brown was 0.012 mg/kg, Volta White was 0.0076, Ashanti Brown was 0.014 mg/kg, Ashanti White was 0.015 mg/kg, Northern Brown was 0.0053 mg/kg, Northern White was 0.0112 mg/kg, presented in table 10. No significant variation ( $p > 0.05$ ) was observed mean concentrations (table 10). The mean concentration for 10 imported rice samples analysed was 0.013 mg/kg, presented in table 11. The Cadmium concentration in both local and foreign rice samples was lower than the Codex maximum allowed value (0.4 mg/kg).

Cadmium concentration in the rice samples was second to Arsenic, which confirms a study that discovered that rice has a higher ability to accumulate As and Cd than other cereals (Williams et al., 2007b). Zhao and Wang (2019) observed that Cadmium and Arsenic have a high risk of soil-food chain transfer in paddy rice systems. According to other studies, Cadmium concentration in rice varies from region to region (Shi et al., 2020). Adomako et al. (2011) discovered that compared to global mean values, Ghanaian rice has lower Cadmium values. Meharge and Rahman (2003) found the highest Cadmium levels in rice grains from Bangladesh and Sri Lanka in a survey they conducted on 12 countries from four continents.

Shi et al. (2020) found low concentration of Cadmium in rice from the European region. Rahman et al. (2014) found higher concentrations of Cadmium in Indian and Thai rice than in Australian rice. Fang and his colleagues found Cadmium concentration in rice to be above maximum allowable concentration from the main rice growing regions in China (Fang et al., 2014). The differences in the concentration levels could be attributed to the bioavailability of Cadmium in soil, rice genotype and growing conditions (Zhao & Wang, 2019). Numerous factors influence

Cadmium bioavailability and uptake by rice, including soil pH, organic matter content, salinity, macro and micronutrient fertilisers, crop species cultivar (Roberts, 2014), cadmium-containing fertilisers and waste from industrial discharges (Tang, 2008). However, Cadmium removal from soil is difficult, but phytoavailability can be controlled (Hu et al., 2016).

Table 10 Cadmium (Cd) content of local rice samples

Heavy Metal	Rice Sample	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)
Cadmium	VB	0.0022	0.0346	0.0118±0.0059
	VW	0.0061	0.0103	0.0076±0.0007
	AB	0.0000	0.0424	0.0135±0.0078
	AW	0.0000	0.0338	0.0157±0.0006
	NB	0.0000	0.0123	0.0059±0.0026
	NW	0.0000	0.0296	0.0112±0.0057

No significant variations between means ( $p>0.05$ ) No. of samples = 30, Codex standard (0.4 mg/kg). VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)

Table 11 Cadmium (Cd) Content of foreign rice samples

Metal Heavy	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Cadmium	0.0130	0	0.03

Number of samples =10

#### 4.3.5 Mercury (Hg)

There were no traces of Mercury in 24 local rice samples analysed, except Volta Brown, Ashanti White, Volta White: one sample each from two separate markets and Ashanti Brown. The maximum concentration of Mercury in the rice samples was 0.064 mg/kg, found in Ashanti Brown. The mean concentration of Mercury in Volta Brown was 0.001 mg/kg, Volta White was 0.007 mg/kg and Ashanti White was 0.013 mg/kg. No significant variation ( $p > 0.05$ ) was observed in the mean concentrations (table 12). There were non detectable limits of Mercury in eight foreign rice samples.

Mercury has very low solubility in soil so plants absorb only very small amounts of it (Zhao & Wang, 2019), which could account for why Mercury was not discovered in most of the rice samples. Traces of Mercury found in foreign rice samples were lower than those found in the local rice samples; 0.001 mg/kg and 0.0004 mg/kg. This implies that Mercury concentration differs from area to area. For instance, Søvik et al., (2011) found higher concentrations of Mercury in rice samples from Wanshan the rice paddy fields in China. On the contrary, Zhao et al., (2019) found low concentration values of Mercury in rice samples collected at 560 sites in 15 provinces across China. Silva et al. (2012) found varied Mercury content in rice samples from Salvador City, Bahia State, Brazil.

Al-Saleh and Shinwari (2001) observed that the differences in Mercury content in rice samples is because different rice grain samples had varying concentrations of Mercury. The transformation and transportation of Mercury in the rice paddy system is significantly influenced by agricultural practices such as fertilizer use, cultivation techniques, and cultivar selection (Tang et al., 2020). Mercury enters the rice paddy system primarily by air deposition, chemical industry emissions,

metal mining and smelting, irrigation of wastewater, and the use of fertilizers and pesticides (Tang et al., 2020).

Table 12 Mercury (Hg) content of local rice samples

Heavy Metal	Rice Sample	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)
Mercury	VB	0.0000	0.0065	0.0013±0.0053
	VW	0.0000	0.0325	0.0068±0.0064
	AB	0.0000	0.0000	0.0000
	AW	0.0000	0.0635	0.013±0.0126
	NB	0.0000	0.0000	0.0000
	NW	0.0000	0.0000	0.0000

No significant variations between means ( $p > 0.05$ ) No. of samples =30 VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)

Table 13 Mercury (Hg) Content of foreign rice samples

Heavy Metal	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Mercury	0.0007	0.0004	0.001

Number of samples =10



#### 4.3.6 Copper (Cu)

Traces of Copper was found in both the local and foreign rice samples analysed. This is mainly because Copper is naturally present in food (ATSDR, 2004). The maximum and minimum concentration of copper was found in two Volta Brown samples as 0.005 mg/kg and 0.000025 mg/kg respectively. The mean concentration of Copper in Volta Brown was 0.0027 mg/kg, Volta White was 0.0025 mg/kg, Ashanti Brown was 0.0023 mg/kg, Ashanti White was 0.0028 mg/kg, Northern Brown was 0.0033 mg/kg, and Northern White was 0.0028 mg/kg. No significant variation ( $p > 0.05$ ) was observed in the mean concentrations (table 14). The maximum and minimum concentrations of copper found in 10 foreign rice samples was 0.0034 and 0.0017 mg/kg respectively.

The maximum concentration of copper was higher in local rice samples than in foreign rice samples. Ketut and Salihat (2021) also discovered lower levels of copper in purple rice samples analysed in Batang Anai District, Indonesia. On the contrary, Anjum & Pasha, (2007) found higher Copper content in four Pakistani coarse rice varieties. In addition, Cui et al., (2019) found higher levels of copper in rice samples in China.

Even though the Codex Alimentarius Commission has not established any criteria for copper, research shows that excessive copper exposure has been connected to cardiovascular toxicity, hypotension, hepatic necrosis, gastrointestinal mucosal ulcerations, and bleeding (Adusei-Mensah et al., 2019). Prolonged contact with copper dust can cause irritation of the nose, mouth, and eyes in addition to headaches, dizziness, nausea, and diarrhea (ATSDR, 2004). The recommended dietary intake is 0.9 mg per day (0.013 mg per kilogram per day) (Tchounwou, Yedjou, et al., 2003). Therefore, if the dietary advice is followed, it is important for the diet as well.

Copper is required as a cofactor for several other oxidases that regulate blood coagulation and blood pressure control, connective tissue cross-linking, energy transformation, brain and spinal cord myelination, reproduction, and hormone synthesis (Collins et al., 2010). Copper is necessary for brain cells because it is a cofactor and structural component of several enzymes involved in energy metabolism pathways (Cendrowska-Pinkosz et al., 2022). Infant development, immune system performance, bone density, maturation of red and white blood cells, iron transport, cholesterol and glucose metabolism, cardiac contractility, and brain development all require copper (Olivares & Uauy, 1996). Enzymes that require copper oversee reducing molecular oxygen (Tchounwou et al., 2008).

Table 14 Copper (Cu) content of local rice samples

Heavy Metal	Rice Sample	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)
Copper	VB	0.0000	0.0050	0.0027±0.0011
	VW	0.0018	0.0035	0.0025±0.0003
	AB	0.0001	0.0039	0.0023±0.0009
	AW	0.0048	0.0016	0.0028±0.0006
	NB	0.0010	0.0041	0.0033±0.0006
	NW	0.0020	0.0033	0.0028±0.0003

No significant variations between means ( $p > 0.05$ ) No. of samples =30 VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)

Table 15 Copper (Cu) Content of foreign rice samples

Heavy Metal	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Copper	0.0026	0.0017	0.0034

Number of samples =10

#### 4.3.7 Zinc (Zn)

Traces of Zinc were found in 29 local samples analysed, except one Volta Brown rice sample. The maximum concentration of Zinc was found in Ashanti Brown (0.027 mg/kg), while the minimum concentration was found in Volta Brown (0.0024 mg/kg). The mean concentration of Zinc in Volta Brown was 0.0128 mg/kg, Volta White was 0.0129 mg/kg, Ashanti Brown was 0.0165 mg/kg, Ashanti White was 0.0130 mg/kg, Northern Brown was 0.0141 mg/kg, and Northern White was 0.0077 mg/kg. No significant variation ( $p > 0.05$ ) was observed in the mean concentrations (table 16). The maximum and minimum concentrations of Zinc found in 10 foreign rice samples was 0.0184 and 0.0093 mg/kg respectively.

Zinc content in rice samples varies from region to region. For instance, Ketut & Salihat, (2021) found 0.1046 mg/kg of Zinc content in the purple broken rice sample in Batang Anai District, Indonesia, which was higher than what was discovered in this study. According to Sanjeeva et al. (2020), zinc levels in polished rice from prominent rice types in India range from (12-14 mg/kg). Joy et al. (2016) discovered that Malawi's 21 white (polished) and 33 brown rice samples had median total zinc contents (mg kg<sup>-1</sup>, dry weight) of 17.0 and 14.4 respectively. The zinc content of grains varies greatly depending on soils, seasons, and agronomic practises (Sanjeeva et al., 2020).

While Codex does not have any standards for Zinc (Codex Alimentarius Commission, 2019), it is a micronutrient that is required by all living organisms (Kumar Sharma & Agrawal, 2004). It is an essential human nutrient that is found in all tissues and serves as a cofactor for over 300 enzymes (US EPA, 2005). Zinc is required for prenatal and perinatal growth, protein synthesis, and DNA and RNA stabilization in both animals and humans (Kumar Sharma & Agrawal, 2004). Dermatitis, anorexia, growth retardation, sluggish wound healing, hypogonadism, which impairs one's capacity to reproduce, immune system dysfunction, and mental deterioration are just a few of the illnesses that have been linked to zinc deficiency (ATSDR, 2005). Congenital abnormalities in newborns are more common when moms are zinc deficient, according to research (ATSDR, 2005). Other substances' ability to cause cancer may also be affected by zinc deficiency, albeit the effect's nature and direction may differ depending on the substance that causes cancer (ATSDR, 2005). It is estimated that individuals consume 5.2-16.2 mg of zinc daily from diet, or 0.07–0.23 mg/kg/day, based on an average body weight of 70 kg (ATSDR, 2005). The recommended dietary allowance (RDA) for zinc, which is 11 mg/day for males and 8 mg/day for women, is about 0.16 mg/kg/day for men and 0.13 mg/kg/day for women (ATSDR, 2005). For women who are pregnant or nursing, higher RDAs (12 mg/day) are advised (ATSDR, 2005). The recommended zinc intake for babies is 2-3 mg/day and for children is 5-9 mg/day due to their lower typical body weights (Trumbo et al., 2001). Ogabiela et al. (2011) found that although zinc has low toxicity in humans, long-term usage of large dosages can result in neutropenia, exhaustion, and other health issues.

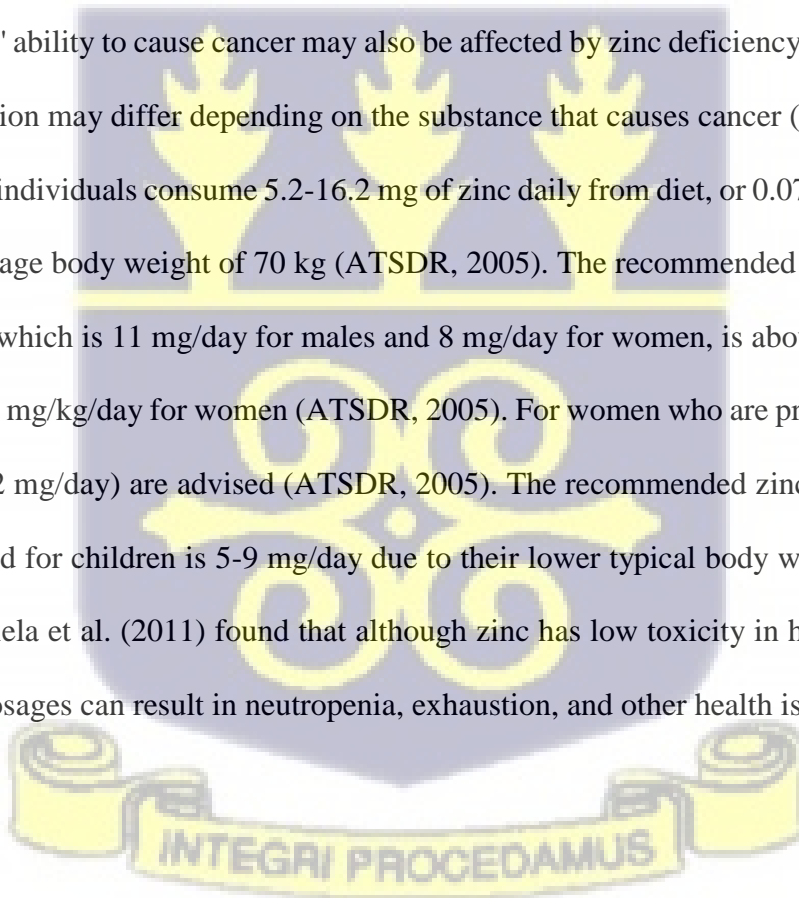


Table 16 Zinc (Zn) content of local rice samples

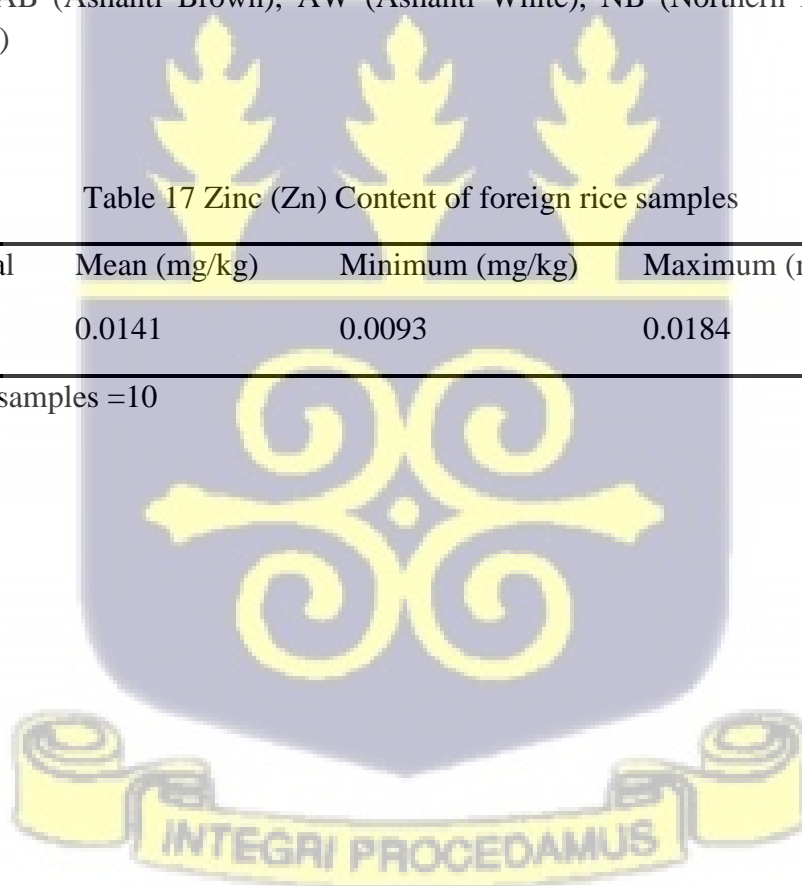
Heavy Metal	Rice Sample	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)
Zinc	VB	0.0000	0.0214	0.0129±0.0048
	VW	0.0117	0.0148	0.0129±0.0006
	AB	0.0030	0.0268	0.0165±0.0038
	AW	0.0094	0.0163	0.013±0.0011
	NB	0.0034	0.0205	0.0141±0.0031
	NW	0.0045	0.0135	0.0077±0.0016

No significant variations between means ( $p>0.05$ ) No. of samples =30. VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)

Table 17 Zinc (Zn) Content of foreign rice samples

Heavy Metal	Mean (mg/kg)	Minimum (mg/kg)	Maximum (mg/kg)
Zinc	0.0141	0.0093	0.0184

Number of samples =10



#### 4.4 Exposure to Heavy Metals from Consumption of Local Rice

In this study, the exposure to heavy metals (Arsenic, Lead, Cadmium, Mercury, Copper, and Zinc) associated with the consumption of local rice sold at markets in the Accra Metropolis were examined. Exposure assessment and Human Risk for each metal was determined using the U.S. EPA approach.

From the results of the consumer survey, participant data on age was grouped as <20 years, 20 – 29 years, 30 –39 years, 40 – 49 years, and above 50 years, respectively (Figure 2). Similarly, age distribution of children in participants households were also grouped as 6 – 11 months, 1–3 years, 4 – 9 years, and 10 –14 years, respectively (Figure 8). The average daily consumption rate (g/d) of local rice for children and adults were 58.33 g and 221.67 g respectively, while average weekly intake was 142.43 g for children and 496.36 g for adults, respectively. The average body weight (BW) for children and adults was 25.5 kg and 64.5 kg, respectively (Table 5).

The estimated daily intake (EDI) of heavy metals (As, Pb, Cd, Hg, Cu, and Zn) from eating local rice sold in Accra Metropolis for adults and kids is shown in Tables 18 and 19. Adults have a greater EDI than kids. All the rice samples had an EDI for As and Cd that was significantly higher than the Reference dose (RfD) (0.0003 mg/kg/day for As and 0.001 mg/kg/day for Cd). Three rice samples (Volta Brown, Ashanti White, and Northern Brown) had EDIs for Lead that were significantly higher than the RfD (0.0035 mg/kg/day), with the highest EDIs for Lead in adults being 0.3423 mg/kg/day and in children being 0.228 mg/kg/day. For adults and kids, the EDI for Mercury in three rice samples (Volta Brown, Volta White, and Ashanti White) was greater than the RfD (0.033 mg/kg/day).

The outcome shows that consumers are exposed to high levels of As, Cd, Pb, and Hg through their diet. The RfD for an essential metal Cu (0.04 mg/kg/day), which was greater than the EDI of

0.0078 to 0.0113 mg/kg/day for adults and 0.005 to 0.008 mg/kg/day for children. The RfD for the essential metal Zn in all samples of rice was also greater (0.04 mg/kg/day) than the EDI, which ranged from 0.0263 to 0.0568 mg/kg/day for adults and 0.018 to 0.038 mg/kg/day for children.

Table 18 Estimated Daily Intake (EDI) of local rice for adults

Estimated Daily Intake (EDI, mg/kg/day)						
Rice Sample	As	Pb	Cd	Hg	Cu	Zn
VB	0.1730	0.0137	0.0404	0.0045	0.0093	0.0441
VW	0.1319	0.0000	0.0261	0.0241	0.0086	0.0445
AB	0.2070	0.0000	0.0481	0.0000	0.0078	0.0568
AW	0.1416	0.0364	0.0526	0.0447	0.0097	0.0448
NB	0.1914	0.3423	0.0182	0.0000	0.0113	0.0485
NW	0.1511	0.0000	0.0385	0.0000	0.0096	0.0263
RfD (mg/kg/day)	0.0003	0.0035	0.001	0.033	0.04	0.3

VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)

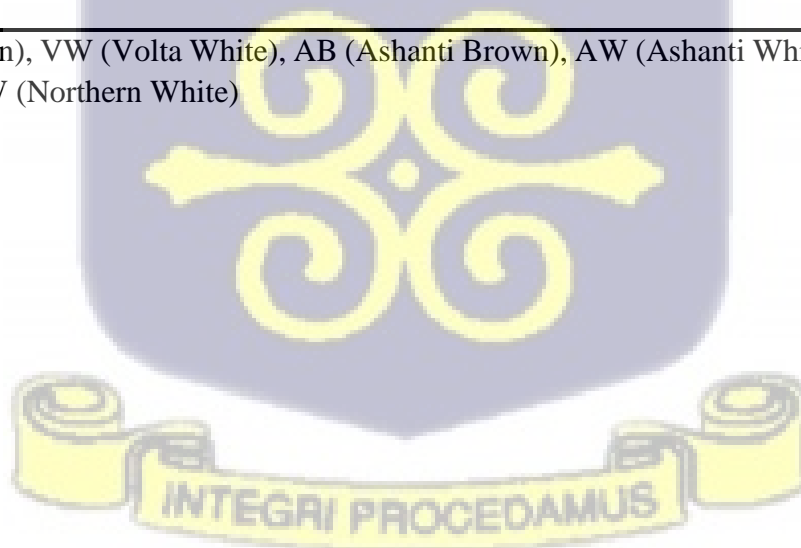


Table 19 Estimated Daily Intake (EDI) of local rice for Children

Estimated Daily Intake (EDI, mg/kg/day)						
Rice Sample	As	Pb	Cd	Hg	Cu	Zn
VB	0.115	0.009	0.027	0.0030	0.006	0.029
VW	0.088	0.000	0.017	0.016	0.006	0.030
AB	0.138	0.000	0.032	0.000	0.005	0.038
AW	0.094	0.024	0.035	0.030	0.006	0.030
NB	0.127	0.228	0.012	0.000	0.008	0.032
NW	0.101	0.000	0.026	0.000	0.006	0.018
RfD (mg/kg/day)	0.0003	0.0035	0.001	0.033	0.04	0.3

VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)

Table 20 and 21 show the estimated weekly intake (EWI) of heavy metals (As, Pb, Cd, Hg, Cu, and Zn) through local rice consumption for adults and children. In both adults and children, the EWI for As and Cd (for all rice samples) was higher than provisional tolerable weekly intake (PTWI) of 0.015 mgkg<sup>-1</sup> BW. The EWI in Arsenic ranges from 0.295 to 0.464 mgkg<sup>-1</sup> BW in adults and 0.214 to 0.336 mgkg<sup>-1</sup> BW in children. The EWI in Cadmium ranges from 0.041 to 0.118 mgkg<sup>-1</sup> BW in adults and 0.030 to 0.086 mgkg<sup>-1</sup> BW in children. The EWI for samples that contain Lead and Mercury was also higher than the PTWI for both adults and children. The highest EWI for Lead found in Northern Brown rice sample (0.766 mgkg<sup>-1</sup> BW and 0.556 mgkg<sup>-1</sup> BW, for adults and children respectively), which was significantly higher than the PTWI (0.025 mgkg<sup>-1</sup> BW). In Mercury, highest EWI was found in Ashanti White rice sample (0.1 mgkg<sup>-1</sup> BW and

0.073 mgkg<sup>-1</sup> BW, for adults and children respectively), which was higher than the PTWI (0.004 mgkg<sup>-1</sup> BW).

However, the EWI for essential nutrients, Copper and Zinc was lower than the PTWI for both adults and children. The trend in the EWI is similar to what was found in the EDI, with the EWI in adults being higher than in children.

Table 20 Estimated Weekly Intake (EWI) of local rice for Adults

Estimated Weekly Intake (EWI, mgkg <sup>-1</sup> BW)						
Rice Sample	AS	Pb	Cd	Hg	Cu	Zn
VB	0.387	0.031	0.090	0.010	0.021	0.099
VW	0.295	0.000	0.059	0.054	0.019	0.100
AB	0.464	0.000	0.108	0.000	0.017	0.127
AW	0.317	0.081	0.118	0.100	0.022	0.100
NB	0.429	0.766	0.041	0.000	0.025	0.109
NW	0.338	0.000	0.086	0.000	0.022	0.059
PWTI	0.015	0.025	0.007	0.004	0.5	0.42

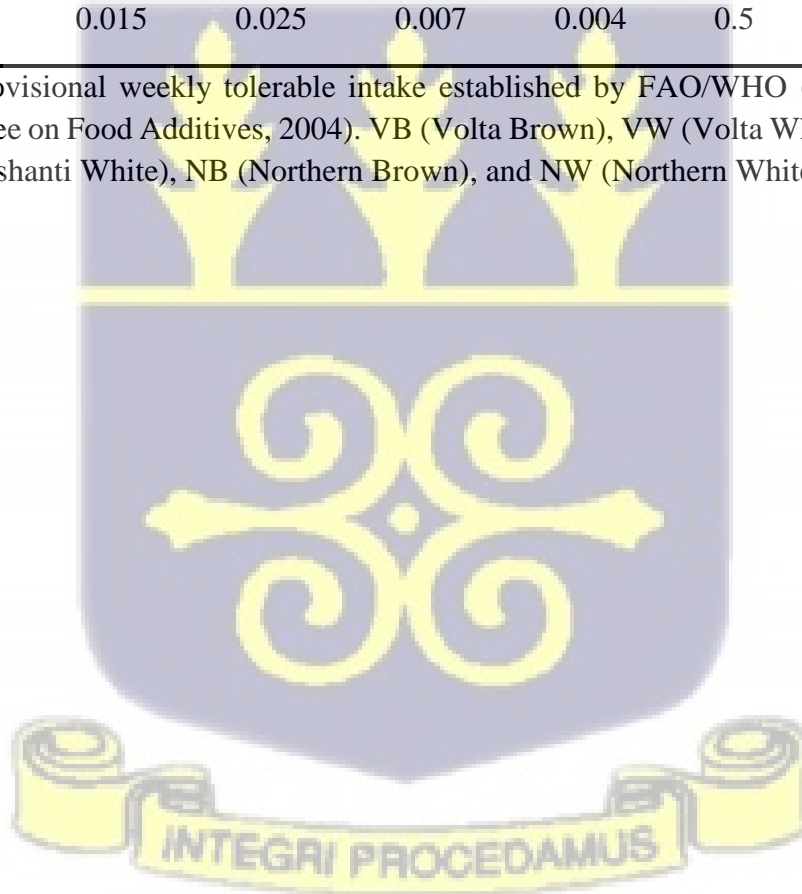
PWTI is the provisional weekly tolerable intake established by FAO/WHO (Joint FAO/WHO Expert Committee on Food Additives, 2004). VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)



Table 21 Estimated Weekly Intake (EWI) of local rice for Children

Estimated Weekly Intake (EWI, mgkg <sup>-1</sup> BW)						
Rice Sample	AS	Pb	Cd	Hg	Cu	Zn
VB	0.281	0.022	0.066	0.007	0.015	0.072
VW	0.214	0.000	0.042	0.039	0.014	0.072
AB	0.336	0.000	0.078	0.000	0.013	0.092
AW	0.230	0.059	0.086	0.073	0.016	0.073
NB	0.311	0.556	0.030	0.000	0.018	0.079
NW	0.246	0.000	0.063	0.000	0.016	0.043
PWTI	0.015	0.025	0.007	0.004	0.5	0.42

PWTI is the provisional weekly tolerable intake established by FAO/WHO (Joint FAO/WHO Expert Committee on Food Additives, 2004). VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)



#### 4.5.1 Non-carcinogenic Risk Assessment (Hazard Quotient)

The Hazard Quotient (HQ) was used as the equation to estimate non-carcinogenic risks:  $HQ = RfD/EDI$ , where the reference dose for each heavy metal under research is RfD (mg kg<sup>-1</sup> day<sup>-1</sup>). (Saha et al., 2016). The HQ serves as a gauge for evaluating potential non-carcinogenic risks to human health. A Hazard Quotient value of one (1) or less posed no projected noncarcinogenic health risk to a population or an individual within that population, in accordance with the US EPA's integrated metal risk assessment system.

To ascertain the possibility for non-cancer hazards because of exposure to more than one heavy metal in a rice sample, the Hazard Index (HI) for each sample, however, was determined. For a population or an individual within that population, a Hazard Index value greater than one (1) denotes a potential noncarcinogenic health risk. To obtain the HI, the values for the HQ of the various heavy metal in each sample of rice were added.

The US EPA Integrated Risk Information System for each metal was used (US EPA, 2015). EDI values for each metal were calculated using the average rice consumption rate, bodyweight (adults and children) and the metal concentrations obtained in this study. The results of HQ for the heavy metals through consumption of local rice by adults and children are presented in Tables 22 and 23, respectively. In adults, values were in the descending order of As > Cd > Pb > Cu > Zn>Hg, however, for children, values were in the descending order of As > Cd > Pb > Hg > Cu>Zn. The HQ for Arsenic (both adults and children) was the highest, which was in the ranges of 439.6 to 690 and 292.6 to 459.3 for adults and children respectively, demonstrating potential non-carcinogenic risks through the consumption of local rice. This corresponds to a finding from Sharafi and his colleagues who also found the highest HQ value in Arsenic, as compared to other metals like Cd and Pb (Sharafi et al., 2019).

In adults, Cadmium followed Arsenic and had HQ values significantly greater than 1 (with range from 18.18 to 52.62), indicating possible non-carcinogenic risks through the consumption of local rice. Traces of Lead were not found in three rice samples, hence the HQ in those samples were zero (Table 22). However, the values for HQ in Pb in the three samples that had traces of Pb were significantly greater than 1 in the descending order, 97.8, 10.4 and 3.9. In Hg, the HQ for all samples were less than 1, except one sample that had a value of 1.35. However, the HQ for Cu and Zn, were significantly less than 1, indicating no potential non-carcinogenic risks posed for adult local rice consumers.

In children, the values for HQ were greater than 1 for Cadmium, with range from 12.1 to 35, demonstrating potential non-carcinogenic risks through the consumption of local rice. Traces of Lead were not found in three rice samples, hence the HQ in those samples were zero. However, in the samples where traces of Pb were found, HQ was greater than 1 in the descending order 65.1, 6.9 and 2.6 (Table 23). In children, Hg, Cu and Zn, have values of their HQ less than 1, showing Hg, Cu and Zn does not pose potential non-carcinogenic risks for children. However, As, Pb and Cd pose potential noncarcinogenic risks for children.

The study's findings are in line with a study conducted in 2021 by Nguyen and his colleagues, which looked for inorganic arsenic (iAs), a type of arsenic with high concentrations, in uncooked rice in Ho Chi Minh City. The inorganic arsenic level in uncooked rice was found to be below the Joint FAO/WHO Expert Committee on Food Additives (JECFA) limits, however the non-carcinogenic health risk caused by iAs from rice consumption is still a public health concern (Nguyen et al., 2019b). Similarly, (Zeng et al., 2015) discovered that the Cd, Hg, and As Hazard Quotient values were larger than 1, indicating potential non-carcinogenic health concerns to the inhabitants of three agricultural areas of Hunan province.

Table 22 Hazard Quotient (HQ) in Adults

Rice sample	Hazard Quotient						HI
	As	Pb	Cd	Hg	Cu	Zn	
VB	576.7	3.9	40.4	0.1	0.232	0.147	621.5
VW	439.6	0	26.1	0.1	0.215	0.148	466.1
AB	690.0	0	43.9	0	0.195	0.149	734.2
AW	471.9	10.4	52.6	1.4	0.242	0.162	536.6
NB	638.0	97.8	18.2	0	0.282	0.048	754.3
NW	503.6	0	38.5	0	0.240	0.088	542.4

HI (hazard index) is the sum of HQ for all the heavy metals in each sample. VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)

The HQ value for all six investigated heavy metals was over the acceptable threshold, which was greater than 1, even though some of the pollutants from heavy metals did not appear to pose particular concerns. This indicated a potential non-carcinogenic harm to human health because of the accumulation of these heavy metal pollutants in the rice. This finding was consistent with a prior study which suggested that local adults and children may be at non-carcinogenic risk from heavy metal exposure (Sibuar et al., 2022a; Zulkafflee et al., 2020). Similar to this, Mao et al., (2019) revealed that Pb and As in rice pose non-carcinogenic risk to people.

Additionally, it was noted by Kulathunga et al. (2022) that the intake of rice in Sri Lanka may provide a health concern due to the presence of Cd, As, and Pb in rice samples. Fan et al. (2017) examined Pb, Cd, and As concentrations in brown rice samples from three heavy metal mining

regions in Hunan Province, central China, and assessed the possible health effects to locals. Their study's conclusions indicated that residents may be at risk for cancer.

Table 23 Hazard Quotient (HQ) in Children

Rice samples	Hazard Quotient						
	As	Pb	Cd	Hg	Cu	Zn	HI
VB	383.7	2.6	26.9	0.1	0.15	0.10	413.6
VW	292.6	0	17.4	0.5	0.14	0.10	310.7
AB	459.3	0	32.0	0	0.13	0.13	491.6
AW	314.1	6.9	35.0	0.90	0.16	0.10	357.2
NB	424.6	65.1	12.1	0	0.19	0.11	502.1
NW	335.2	0	25.6	0	0.16	0.06	361.0

HI is the Hazard index for all the heavy metals in each sample. VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)

#### 4.5.2 Carcinogenic Risk Assessment

The danger of acquiring cancer during one's lifetime because of exposure to a possible carcinogen is known as the carcinogenic risk. In this study, incremental lifetime cancer risk values were used to calculate the carcinogenic health risk that heavy metal polluted rice poses to consumers. The estimated daily intake (EDI) (mg/kg/BW/day) and the slope factors of the different metals (As=1.5, Cd=15, Pb=0.0085) were used to assess the cancer risk (U.S. EPA, 1988).

An incremental lifetime cancer risk value of  $1 \times 10^{-4}$  or more is deemed dangerous and should raise public health concerns, according to the US EPA metal risk guideline (US EPA, 2015). Any

Incremental Lifetime Cancer Risk value of  $1 \times 10^{-6}$  or less is considered safe and poses no significant expected carcinogenic health risk to a population (US EPA, 2007).

To assess their potential carcinogenic effect on adults and children through intake of local rice, the lifetime cancer risk (LCR) for As, Pb, and Cd was computed. The results are displayed in Tables 24 and 25, respectively. When it comes to heavy metals, an Incremental Lifetime Cancer Risk (ILCR) of less than  $1 \times 10^{-6}$  (0.000001) is seen as negligible and the cancer risk can be disregarded; however, an ILCR of more than  $1 \times 10^{-4}$  (0.0001) is regarded as hazardous and the cancer risk is problematic. The findings of this investigation demonstrated that, for both adults and children, the LCR values for As, Pb, and Cd were greater than the permissible limit. Only the LCR for Pb came close to being equal to 0.0001. This shows that there was a likelihood of developing cancer in consumers (both adults and children), through exposure to As, Pb and Cd in local rice.

These results were consistent with past research that showed eating rice could expose people to heavy metals, which could increase their risk of developing cancer (Kulathunga et al., 2022; Sibuar et al., 2022; Zulkafflee et al., 2020, 2022). The carcinogenic risk of arsenic in three types of rice was also found to be greater than the permissible level (104), according to Sharafi et al., (2019).<sup>1</sup>s analysis. For Pb, Cd, and As in rice consumed in three heavy metal mining sites in Hunan Province, Fan and his colleagues looked into Incremental Lifetime Cancer Risks values. Results of their research showed that locals may be at risk for carcinogenic health problems (Fan et al., 2017). According to a study from Biswas and his colleagues in 2021, arsenic exposure from rice consumption may pose a carcinogenic health risk to the people of rural Bengal (Biswas et al., 2021).

Further, Mao et al., (2019) reported that Cd and As in rice pose carcinogenic risks to humans consumers. A study from carcinogenic risk assessment by Fahri et al. (2018) showed minimum

and maximum incremental lifetime cancer risk among the population of the north regions of Iran. Likewise, Zeng et al., (2015) found Cd and As Cancer Risk values to greater than  $10^{-4}$ , indicating potential carcinogenic health risks to the residents in three agricultural areas of Hunan province. As, Pb, Cr and Cd are examples of heavy metals that may increase a person's risk of developing cancer (Cao et al., 2014; Wcislo et al., 2002). Therefore, many different types of cancer may develop after prolonged exposure to little levels of hazardous metals (Mohammadi et al., 2019).

Table 24 Cancer Risk (CR) in Adults

Rice Sample	Cancer Risk		
	AS	Pb	Cd
VB	0.25930	0.00012	0.60606
VW	0.19780	0.00000	0.39223
AB	0.31056	0.00000	0.72172
AW	0.21238	0.00021	0.78933
NB	0.28709	0.00194	0.27268
NW	0.22661	0.00000	0.57716

VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)



Table 25 Cancer Risk (CR) in Children

Rice samples	Cancer Risk		
	As	Pb	Cd
VB	0.17268	0.00008	0.40339
VW	0.13165	0.00000	0.26106
AB	0.20671	0.00000	0.48037
AW	0.14136	0.00021	0.52537
NB	0.19109	0.00194	0.18149
NW	0.15083	0.00000	0.38415

VB (Volta Brown), VW (Volta White), AB (Ashanti Brown), AW (Ashanti White), NB (Northern Brown), and NW (Northern White)



## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATION

#### 5.1 Conclusion

This study's goal was to assess how much local rice sold in Accra Metropolis exposes consumers to various heavy metals, including arsenic, lead, cadmium, mercury, copper, and zinc. Adults with a body weight between 60 and 69 kg consumed an average of 496.36 g per week and 221.67 grams per day, according to a consumer survey. Children's average weight was between 21 and 30 kg, and their average daily and weekly intake was 58.33 and 142.43 grams, respectively.

The concentration of As, Pb, Cd, Hg, Cu, and Zn in each of the 30 samples of rice was found to be below the Codex Alimentarius Commission's maximum allowable level except for one sample.

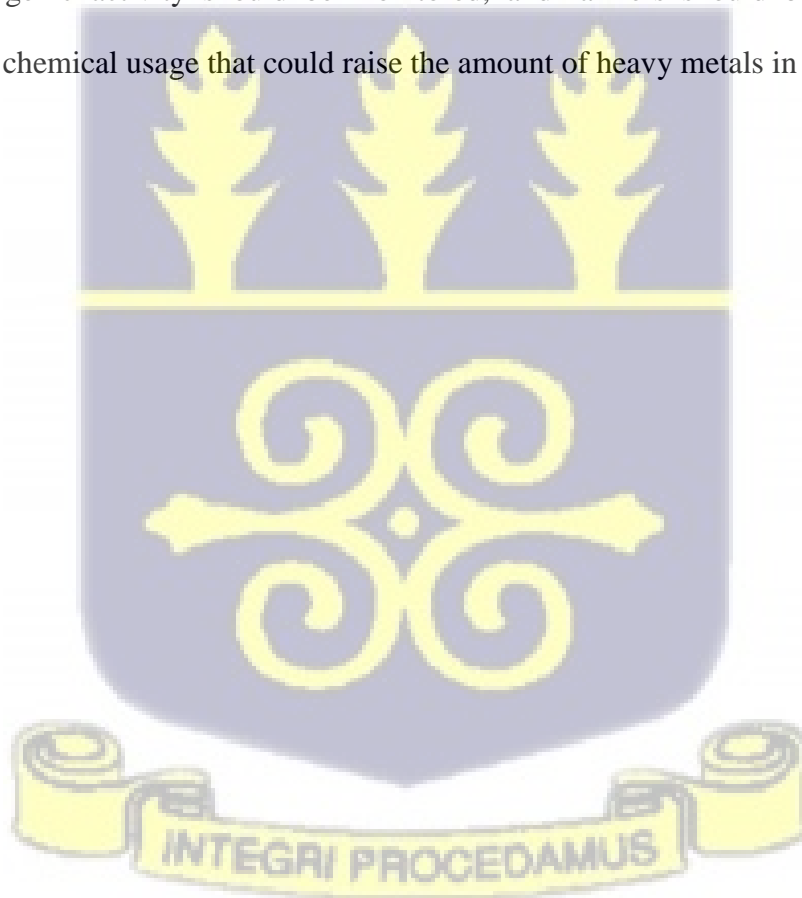
However, a health risk assessment found the possibility of both cancerous and noncancerous dangers in both adults and children from consuming locally produced rice. As, Pb, and Cd for both adults and children were the main causes for worry. As, Pb, and Cd had computed non-carcinogenic and carcinogenic risks that were higher than the advised standard values. The concentration of important nutrients like Cu and Zn was also discovered to be lower than that of the other metals.



## 5.2 Recommendations

From the research discussions and findings mentioned this study makes the following recommendations:

1. To safeguard consumer health, strong controls should be in place for the security of food crops farmed in Ghana which can help improve upon domestication.
2. The dangers of heavy metal exposure should be widely publicized, and more research should be done on locally produced foods to see how much exposure they have, especially other staple foods.
3. Anthropogenic activity should be monitored, and farmers should be informed about probable chemical usage that could raise the amount of heavy metals in food items.



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[https://doi.org/10.1021/ES070627I/SUPPL\\_FILE/ES070627ISI20070617\\_122802.PDF](https://doi.org/10.1021/ES070627I/SUPPL_FILE/ES070627ISI20070617_122802.PDF)

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## APPENDIX

### APPENDIX I

Dear Participant,

The objective of this research is to assess the risk of exposure to some heavy metals due to consumption of local rice within the Accra Metropolis. This questionnaire seeks to obtain information on rice consumption with emphasis on locally produced rice. Your participation in this study is voluntary. Any information you provide will be kept confidential. It will take you about 15 minutes to complete the questionnaire. Your participation is important and your cooperation is well appreciated.

Thank You.

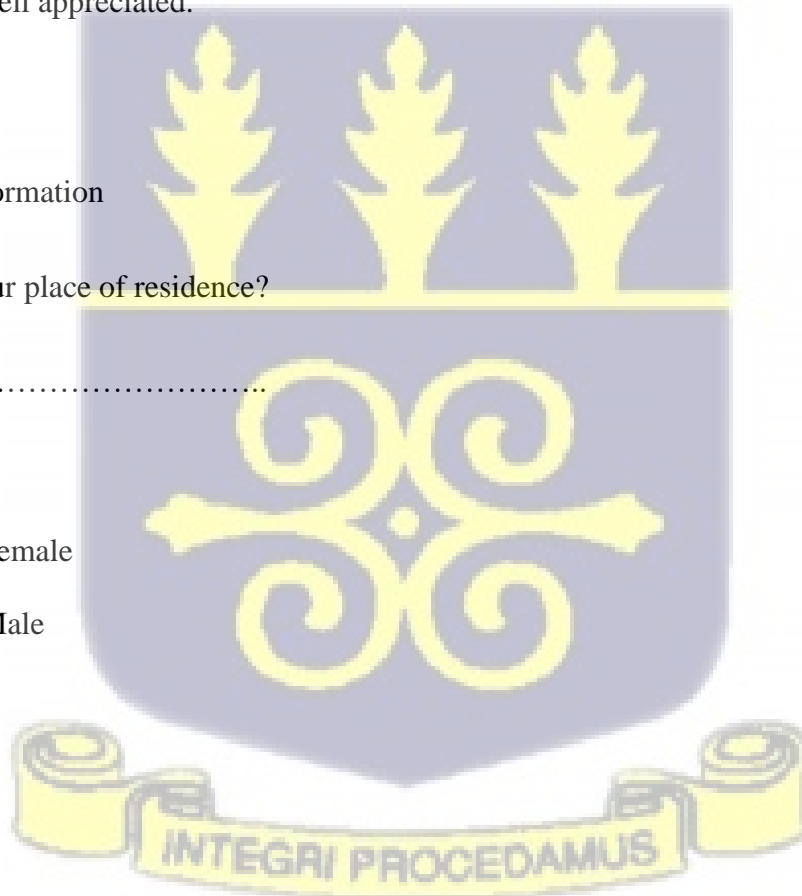
#### Background Information

1. Where is your place of residence?

.....

2. Gender?

- a. Female
- b. Male



3. Age group?

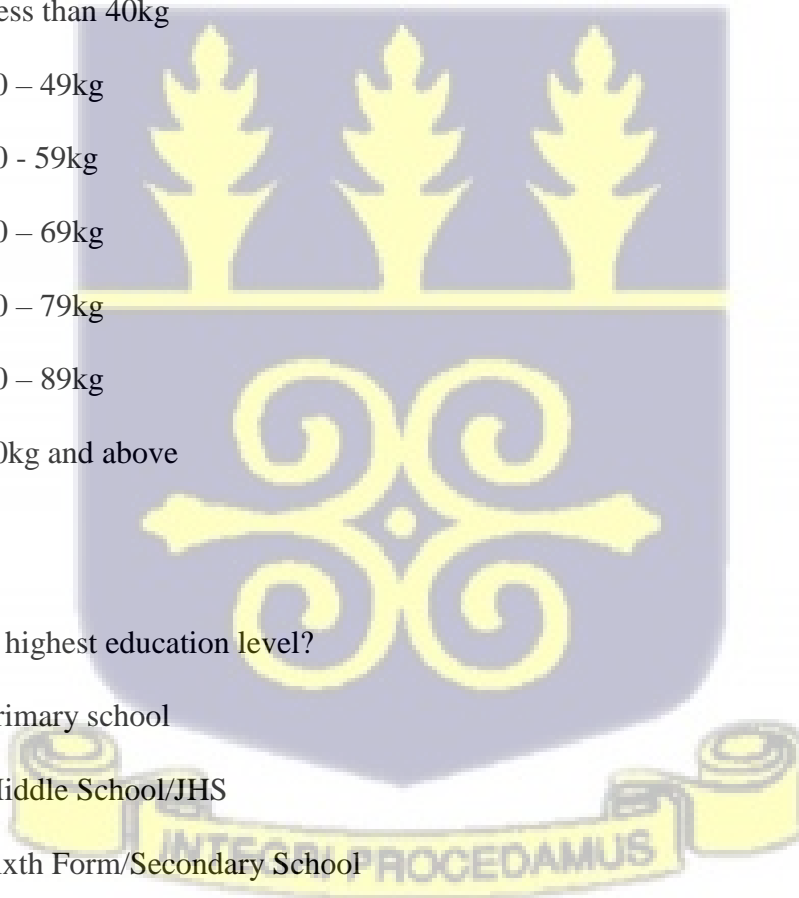
- a. Less than 20 years
- b. 20 – 29 years
- c. 30 – 39 years
- d. 40 – 49 years
- e. 50 and above

4. Body weight?

- a. Less than 40kg
- b. 40 – 49kg
- c. 50 - 59kg
- d. 60 – 69kg
- e. 70 – 79kg
- f. 80 – 89kg
- g. 90kg and above

5. What is your highest education level?

- a. Primary school
- b. Middle School/JHS
- c. Sixth Form/Secondary School
- d. Tertiary
- e. None or other (specify)



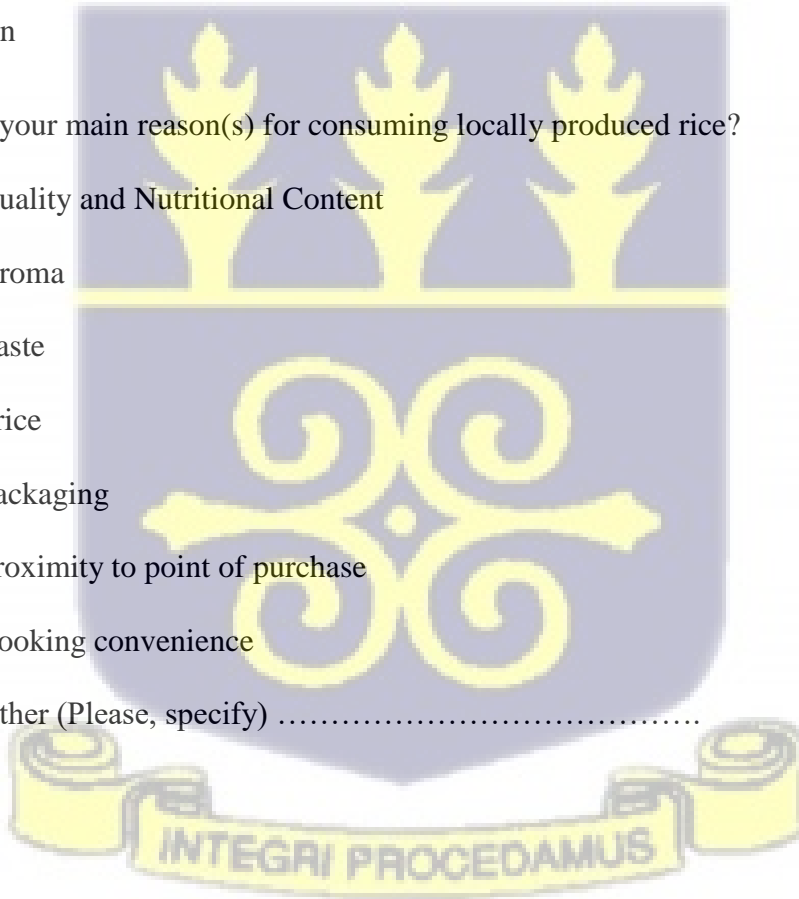
6. What is your occupation?

- a. Student
- b. Unemployed
- c. Employed
- d. Retired
- e. Other (please specify)

Rice consumption

7. What is(are) your main reason(s) for consuming locally produced rice?

- a. Quality and Nutritional Content
- b. Aroma
- c. Taste
- d. Price
- e. Packaging
- f. Proximity to point of purchase
- g. Cooking convenience
- h. Other (Please, specify) .....



8. Where do you purchase the rice?

- a. Local open market
- b. Convenient store/supermarket/shopping mall
- c. Restaurant or food joints
- d. Other (please specify) .....

9. How often do you eat local rice?

- a. Daily
- b. Weekly
- c. Monthly
- d. Yearly
- e. Other (specify) .....

10. How much do you consume per meal or at an instance?



With the above image as a guide which shows one (1) cup of cooked rice which is also equivalent to 175g kindly select the appropriate option based on your consumption.

- a. 1cup = 175g
- b. 1 and 1/2cups = 262.5g
- c. 2cups = 350g
- d. 2 and 1/2cups = 437.5g
- e. 3 cups = 525g
- f. Above 3cups

Consumption by High-Risk Group (Children)

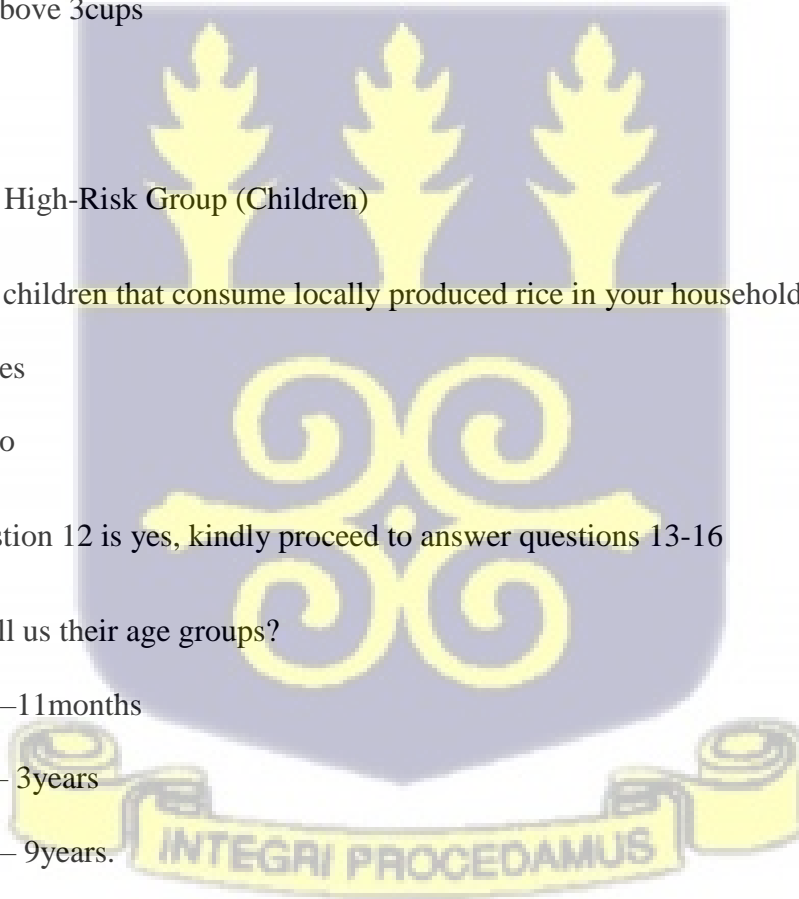
11. Do you have children that consume locally produced rice in your household?

- a. Yes
- b. No

If answer to question 12 is yes, kindly proceed to answer questions 13-16

12. Could you tell us their age groups?

- a. 6–11months
- b. 1–3years
- c. 4–9years.
- d. 10–14years

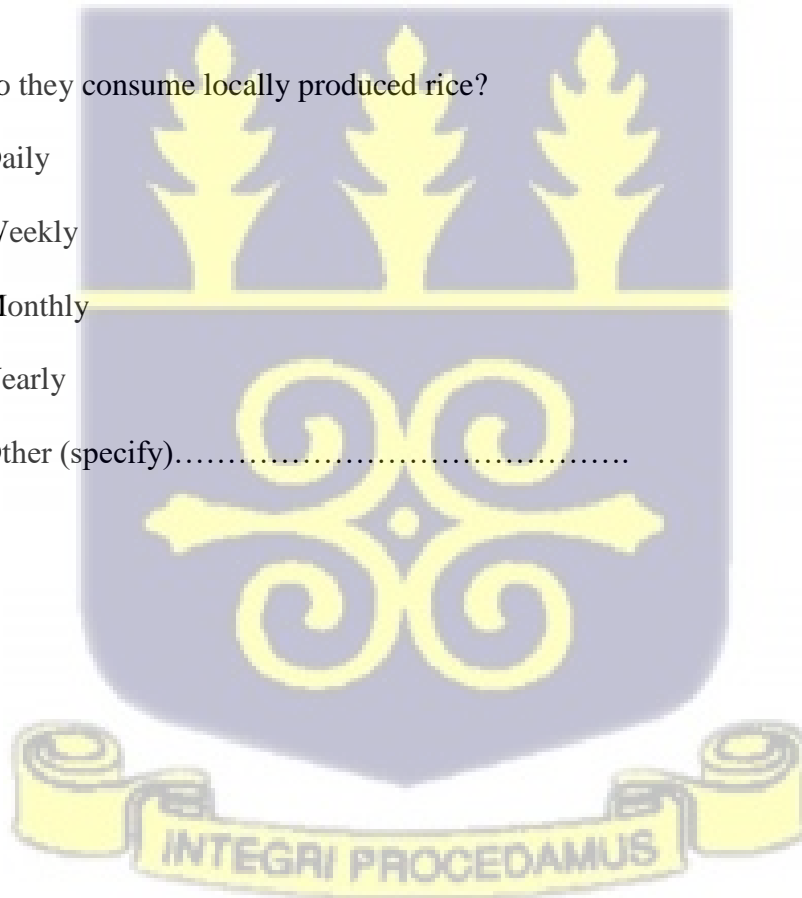


13. Can you tell us their body weight?

- a. Less than 5kg
- b. 5 - 10kg
- c. 11 – 20kg
- d. 21 – 30kg
- e. 31 – 40kg
- f. 41 – 50kg
- g. Above 50kg

14. How often do they consume locally produced rice?

- a. Daily
- b. Weekly
- c. Monthly
- d. Yearly
- e. Other (specify).....



15. How much do they consume per meal or at an instance?



With the above image as a guide which shows one (1) cup of cooked rice which is also equivalent to 175g kindly select the appropriate option based on your consumption.

- a.  $\frac{1}{4}$  cup = 87.5g
- b.  $\frac{1}{2}$  cup = 87.5g
- c. 1 cup = 175g
- d.  $1\frac{1}{2}$  cup = 262.5g
- e. 2 cups and above



**APPENDIX II**

**UNIVERSITY OF GHANA**



Official only Protocol number	Use
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**COLLEGE OF BASIC AND APPLIED SCIENCES**

**Ethics Committee for Basic and Applied Sciences (ECBAS)**

PROTOCOL CONSENT FORM

Section A- BACKGROUND INFORMATION

Title of study:	Exposure Assessment of some Heavy Metals (Arsenic, Lead, Cadmium, Mercury, Copper And Zinc) in Locally Produced Rice sold In Accra Metropolis
Principal Investigator:	Mr. Desmond Asante Karikari
Certified Protocol Number	

Section B– CONSENT TO PARTICIPATE IN RESEARCH

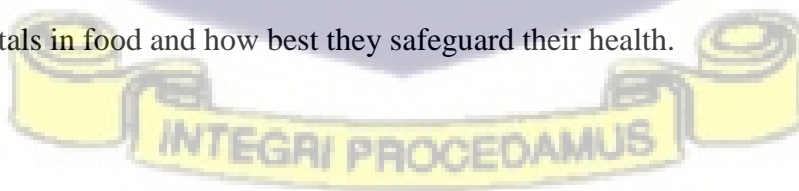
GENERAL INFORMATION ABOUT RESEARCH

The objective of this research is estimating the risk of exposure to some heavy metals due to consumption of local rice within the Accra Metropolis. This questionnaire seeks to obtain information on rice consumption with emphasis on locally produced rice. Your participation in this study is voluntary. Any information you provide will be kept confidential. It will take you about 15 minutes to complete the questionnaire. Your participation is important and your cooperation is well appreciated.

Thank You.

BENEFITS OF THE STUDY

Undertaking this exercise will help to obtain information on local rice consumption, and the risk associated with exposure to heavy metals in the rice. This will also serve as basis to educate local rice farmers on the impact of some of their activities the safety of rice. This will guide stakeholders to provide support for farmers so as to ensure locally produced are free from heavy metals contamination. Ultimately, the outcome of the study will inform consumers the possible health risk of heavy metals in food and how best they safeguard their health.



## RISK OF THE STUDY

The only anticipated risk is COVID 19 transmission during administration of questionnaire to participants. However due to its prevalence all COVID safety protocols will be adhered to. Participation in the consumer survey (using questionnaire) on local rice consumption is voluntary and participants will be required to consent.

## CONFIDENTIALITY

Information provided in this study by participants will be treated as confidential. Under no circumstance will information received be shared with any other person before, during, and after the study is conducted successfully.

## COMPENSATION

Participants in this study will not receive any kind of compensation (cash or gift).

## WITHDRAWAL FROM STUDY

Participation in this study is voluntary. However, you are entitled to pull out from the study at any point in time. You also have the right to choose not to answer any question(s) you find uncomfortable. Your decision not to participate would not affect you in any way or result in any cost incurred. However, you are much encouraged to participate fully in this study.



CONTACT FOR ADDITIONAL INFORMATION

For information, questions and any other related issue about this survey please contact

Dr. Bennett Dzandu

Department of Nutrition and Food Science

University of Ghana

P. O. Box LG 134, Legon

Email: [badzandu@ug.edu.gh](mailto:badzandu@ug.edu.gh)

Tel: 0504714855

If you have any issues on your rights as a participant, you can contact the address below:

Administrator, Ethics Committee for Basic and Applied Sciences

College of Basic and Applied Sciences

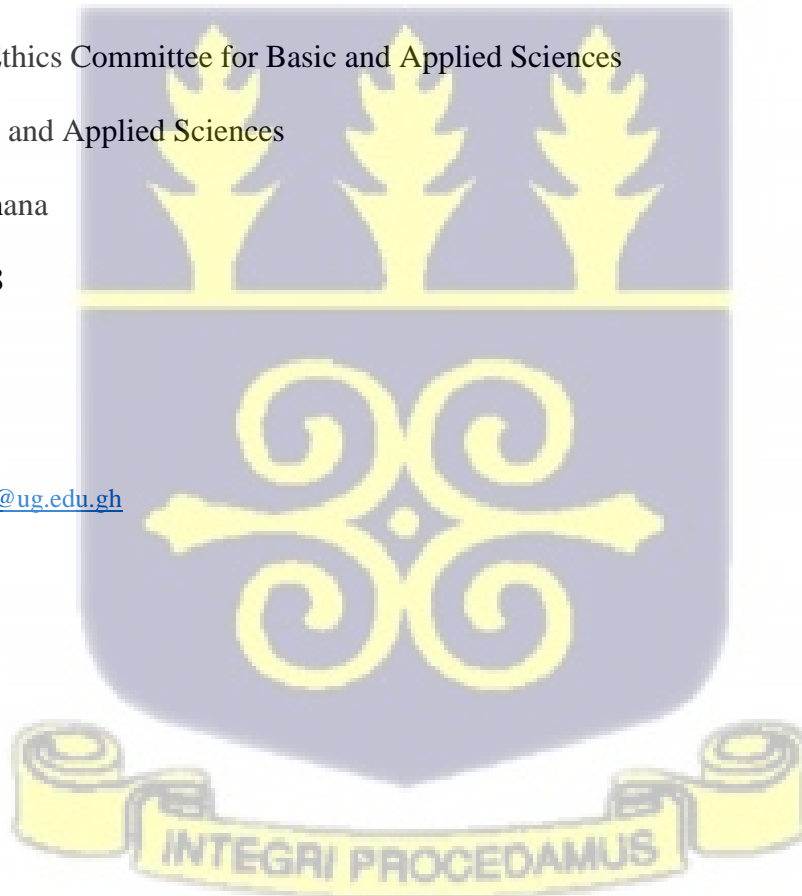
University of Ghana

P. O. Box LG 68

Legon – Accra

IP No.: 3014

Email: [ethicscbas@ug.edu.gh](mailto:ethicscbas@ug.edu.gh)



Section C- VOLUNTEER AGREEMENT

"I have read or have had someone read all of the above, asked questions, received answers regarding participation in this study, and I am willing to give consent for me, my child/ward to participate in this study. I have not waived any of my rights by signing this consent form. Upon signing this consent form, I will receive a copy for my personal records."

---

Name of Volunteer

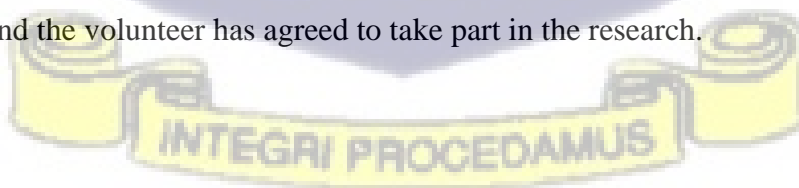
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Signature or mark of volunteer

Date

If volunteers cannot read the form themselves, a witness must sign here:

I was present while the benefits, risks and procedures were read to the volunteer. All questions were answered and the volunteer has agreed to take part in the research.



Name of witness

---

Signature of witness

Date

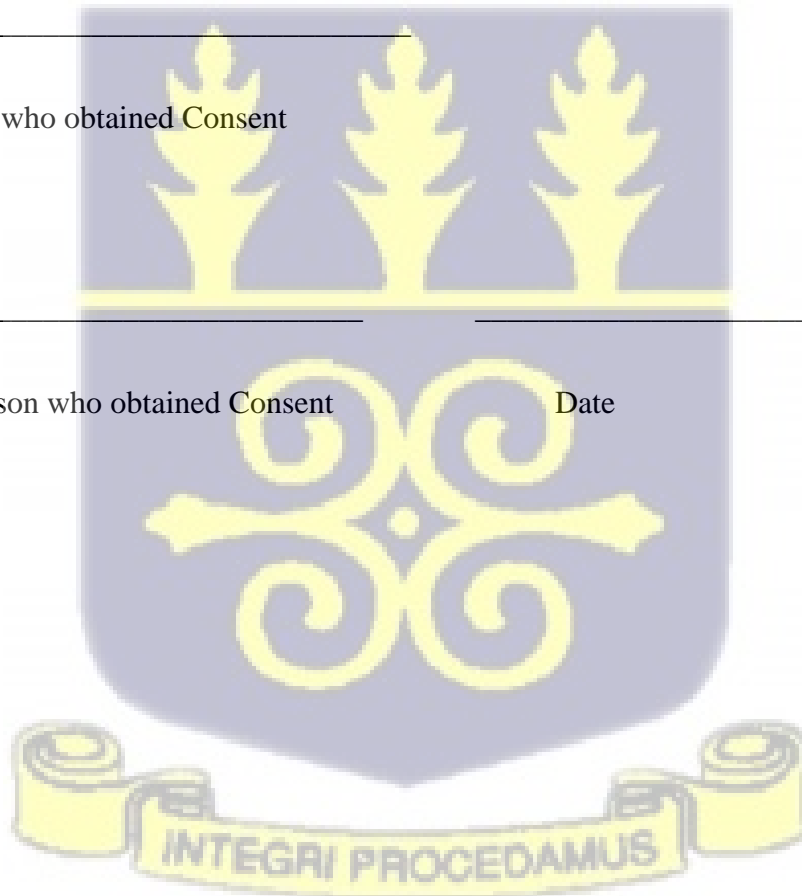
I certify that the nature and purpose, the potential benefits, and possible risks associated with participating in this research have been explained to the above individual.

Name of Person who obtained Consent

---

Signature of Person who obtained Consent

Date



**APPENDIX III**

Analysis of Variance for Arsenic (As) Concentrations of local rice samples

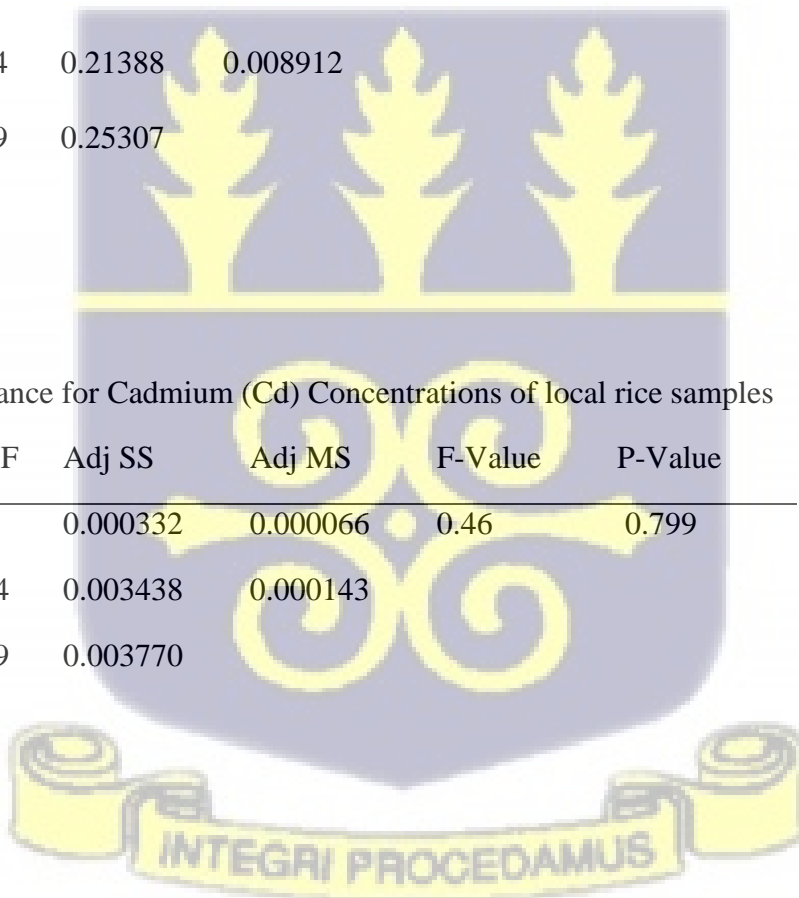
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	5	0.001846	0.000369	0.38	0.855
Error	24	0.023080	0.000962		
Total	29	0.024926			

Analysis of Variance for Lead (Pb) Concentrations of local rice samples

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	5	0.03919	0.007839	0.88	0.510
Error	24	0.21388	0.008912		
Total	29	0.25307			

Analysis of Variance for Cadmium (Cd) Concentrations of local rice samples

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	5	0.000332	0.000066	0.46	0.799
Error	24	0.003438	0.000143		
Total	29	0.003770			



Analysis of Variance for Mercury (Hg) Concentrations of local rice samples

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	5	0.000717	0.000143	0.85	0.528
Error	24	0.004053	0.000169		
Total	29	0.004770			

Analysis of Variance for Copper (Cu) Concentrations of local rice samples

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	5	0.000003	0.000001	0.25	0.934
Error	24	0.000054	0.000002		
Total	29	0.000057			

Analysis of Variance for Zinc (Zn) Concentrations of local rice samples

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	5	0.000210	0.000042	0.97	0.453
Error	24	0.001032	0.000043		
Total	29	0.001242			



**APPENDIX IV**

**Exposure Assessment Among Adults**

Heavy Metal	Rice Sample	IR (g/d)	ED (yrs)	C (mg/kg)	BW (kg)	EF (d/yr)	AT	EDI	HQ	CR
As	VB	221.67	64.68	0.05033	64.5	365	23608.2	0.17296	576.528	0.25944
	VW	221.67	64.68	0.03837	64.5	365	23608.2	0.13187	439.558	0.1978
	AB	221.67	64.68	0.06024	64.5	365	23608.2	0.20704	690.14	0.31056
	AW	221.67	64.68	0.0412	64.5	365	23608.2	0.14159	471.957	0.21238
	NB	221.67	64.68	0.05569	64.5	365	23608.2	0.1914	637.988	0.28709
	NW	221.67	64.68	0.04396	64.5	365	23608.2	0.15107	503.582	0.22661
Pb	VB	221.67	64.68	0.004	64.5	365	23608.2	0.01375	3.92771	0.00012
	VW	221.67	64.68	0	64.5	365	23608.2	0	0	0
	AB	221.67	64.68	0	64.5	365	23608.2	0	0	0
	AW	221.67	64.68	0.01058	64.5	365	23608.2	0.03637	10.3922	0.00031
	NB	221.67	64.68	0.0996	64.5	365	23608.2	0.3423	97.7999	0.00291
	NW	221.67	64.68	0	64.5	365	23608.2	0	0	0
Cd	VB	221.67	64.68	0.01176	64.5	365	23608.2	0.0404	40.4043	0.60606
	VW	221.67	64.68	0.00761	64.5	365	23608.2	0.02615	26.1488	0.39223
	AB	221.67	64.68	0.01278	64.5	365	23608.2	0.04393	43.9253	0.65888
	AW	221.67	64.68	0.01531	64.5	365	23608.2	0.05262	52.6219	0.78933
	NB	221.67	64.68	0.00529	64.5	365	23608.2	0.01818	18.1784	0.27268
	NW	221.67	64.68	0.0112	64.5	365	23608.2	0.03848	38.4771	0.57716

Hg	VB	221.67	64.68	0.0013	64.5	365	23608.2	0.00447	0.13539	N/A
	VW	221.67	64.68	0.007	64.5	365	23608.2	0.02406	0.72901	N/A
	AB	221.67	64.68	0	64.5	365	23608.2	0	0	N/A
	AW	221.67	64.68	0.013	64.5	365	23608.2	0.04468	1.35387	N/A
	NB	221.67	64.68	0	64.5	365	23608.2	0	0	N/A
	NW	221.67	64.68	0	64.5	365	23608.2	0	0	N/A
Cu	VB	221.67	64.68	0.0027	64.5	365	23608.2	0.00929	0.23216	N/A
	VW	221.67	64.68	0.00251	64.5	365	23608.2	0.00862	0.21546	N/A
	AB	221.67	64.68	0.00227	64.5	365	23608.2	0.0078	0.19491	N/A
	AW	221.67	64.68	0.00281	64.5	365	23608.2	0.00966	0.24159	N/A
	NB	221.67	64.68	0.00328	64.5	365	23608.2	0.01127	0.28177	N/A
	NW	221.67	64.68	0.0028	64.5	365	23608.2	0.00961	0.24024	N/A
Zn	VB	221.67	64.68	0.01282	64.5	365	23608.2	0.04408	0.14692	N/A
	VW	221.67	64.68	0.01294	64.5	365	23608.2	0.04446	0.14819	N/A
	AB	221.67	64.68	0.01652	64.5	365	23608.2	0.05676	0.1892	N/A
	AW	221.67	64.68	0.01302	64.5	365	23608.2	0.04475	0.14918	N/A
	NB	221.67	64.68	0.0141	64.5	365	23608.2	0.04847	0.16155	N/A
	NW	221.67	64.68	0.00767	64.5	365	23608.2	0.02634	0.08781	N/A

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Total number of samples = 30

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ESTIMATED DAILY INTAKE (mgkg<sup>-1</sup> BW day<sup>-1</sup>) (EDI) = (C×IR×ED×EF)/(BW×AT)

Where; C = mean concentration

IR = Ingestion Rate for Adults 221.67g/d

ED = Exposure Duration (Life expectancy in Ghana 64.68yrs)

EF = Exposure Frequency 365days/yr

BW = Average Body Weight for Adults 64.5g

AT = Average Time of Exposure 64.68x365

HAZARD QUOTIENT (HQ) = EDI/RfD

Where; RfD Reference Dose for each metal mg/kg/day

As= 0.0003    Pb = 0.0035    Cd = 0.001    Hg = 0.033    Zn = 0.3    Cu = 0.04

CANCER RISK

CR = EDI x SF

where; SF is slope factor for each metal mg/kg/day

As = 1.5    Cd = 15    Pb = 0.0085    Hg = N/A    Zn = N/A    Cu = N/A



**Exposure Assessment Among Children**

Heavy Metal	Rice Sample	IR (g/d)	ED (yrs)	C (mg/kg)	BW (kg)	EF (d/yr)	AT	EDI	HQ	CR
As	VB	221.67	64.68	0.05033	64.5	365	23608.2	0.17296	576.528	0.25944
	VW	221.67	64.68	0.03837	64.5	365	23608.2	0.13187	439.558	0.1978
	AB	221.67	64.68	0.06024	64.5	365	23608.2	0.20704	690.14	0.31056
	AW	221.67	64.68	0.0412	64.5	365	23608.2	0.14159	471.957	0.21238
	NB	221.67	64.68	0.05569	64.5	365	23608.2	0.1914	637.988	0.28709
	NW	221.67	64.68	0.04396	64.5	365	23608.2	0.15107	503.582	0.22661
Pb	VB	221.67	64.68	0.004	64.5	365	23608.2	0.01375	3.92771	0.00012
	VW	221.67	64.68	0	64.5	365	23608.2	0	0	0
	AB	221.67	64.68	0	64.5	365	23608.2	0	0	0
	AW	221.67	64.68	0.01058	64.5	365	23608.2	0.03637	10.3922	0.00031
	NB	221.67	64.68	0.0996	64.5	365	23608.2	0.3423	97.7999	0.00291
	NW	221.67	64.68	0	64.5	365	23608.2	0	0	0
Cd	VB	221.67	64.68	0.01176	64.5	365	23608.2	0.0404	40.4043	0.60606
	VW	221.67	64.68	0.00761	64.5	365	23608.2	0.02615	26.1488	0.39223
	AB	221.67	64.68	0.01278	64.5	365	23608.2	0.04393	43.9253	0.65888
	AW	221.67	64.68	0.01531	64.5	365	23608.2	0.05262	52.6219	0.78933
	NB	221.67	64.68	0.00529	64.5	365	23608.2	0.01818	18.1784	0.27268
	NW	221.67	64.68	0.0112	64.5	365	23608.2	0.03848	38.4771	0.57716

Hg	VB	221.67	64.68	0.0013	64.5	365	23608.2	0.00447	0.13539	N/A
	VW	221.67	64.68	0.007	64.5	365	23608.2	0.02406	0.72901	N/A
	AB	221.67	64.68	0	64.5	365	23608.2	0	0	N/A
	AW	221.67	64.68	0.013	64.5	365	23608.2	0.04468	1.35387	N/A
	NB	221.67	64.68	0	64.5	365	23608.2	0	0	N/A
	NW	221.67	64.68	0	64.5	365	23608.2	0	0	N/A
Cu	VB	221.67	64.68	0.0027	64.5	365	23608.2	0.00929	0.23216	N/A
	VW	221.67	64.68	0.00251	64.5	365	23608.2	0.00862	0.21546	N/A
	AB	221.67	64.68	0.00227	64.5	365	23608.2	0.0078	0.19491	N/A
	AW	221.67	64.68	0.00281	64.5	365	23608.2	0.00966	0.24159	N/A
	NB	221.67	64.68	0.00328	64.5	365	23608.2	0.01127	0.28177	N/A
	NW	221.67	64.68	0.0028	64.5	365	23608.2	0.00961	0.24024	N/A
Zn	VB	221.67	64.68	0.01282	64.5	365	23608.2	0.04408	0.14692	N/A
	VW	221.67	64.68	0.01294	64.5	365	23608.2	0.04446	0.14819	N/A
	AB	221.67	64.68	0.01652	64.5	365	23608.2	0.05676	0.1892	N/A
	AW	221.67	64.68	0.01302	64.5	365	23608.2	0.04475	0.14918	N/A
	NB	221.67	64.68	0.0141	64.5	365	23608.2	0.04847	0.16155	N/A
	NW	221.67	64.68	0.00767	64.5	365	23608.2	0.02634	0.08781	N/A

Total number of samples = 30

ESTIMATED DAILY INTAKE (mgkg<sup>-1</sup> BW day<sup>-1</sup>) (EDI) = (C×IR×ED×EF)/(BW×AT)

Where; C = mean concentration

IR = Ingestion Rate for Adults 221.67g/d

ED = Exposure Duration (Life expectancy in Ghana 64.68yrs)

EF = Exposure Frequency 365days/yr

BW = Average Body Weight for Adults 64.5g

AT = Average Time of Exposure 64.68x365

HAZARD QUOTIENT (HQ) = EDI/RfD

where; RfD Reference Dose for each metal mg/kg/day

As= 0.0003    Pb = 0.0035    Cd = 0.001    Hg = 0.033    Zn = 0.3    Cu = 0.04

CANCER RISK

CR = EDI x SF

where; SF is slope factor for each metal mg/kg/day

As = 1.5    Cd = 15    Pb = 0.0085    Hg = N/A    Zn = N/A    Cu = N/A

