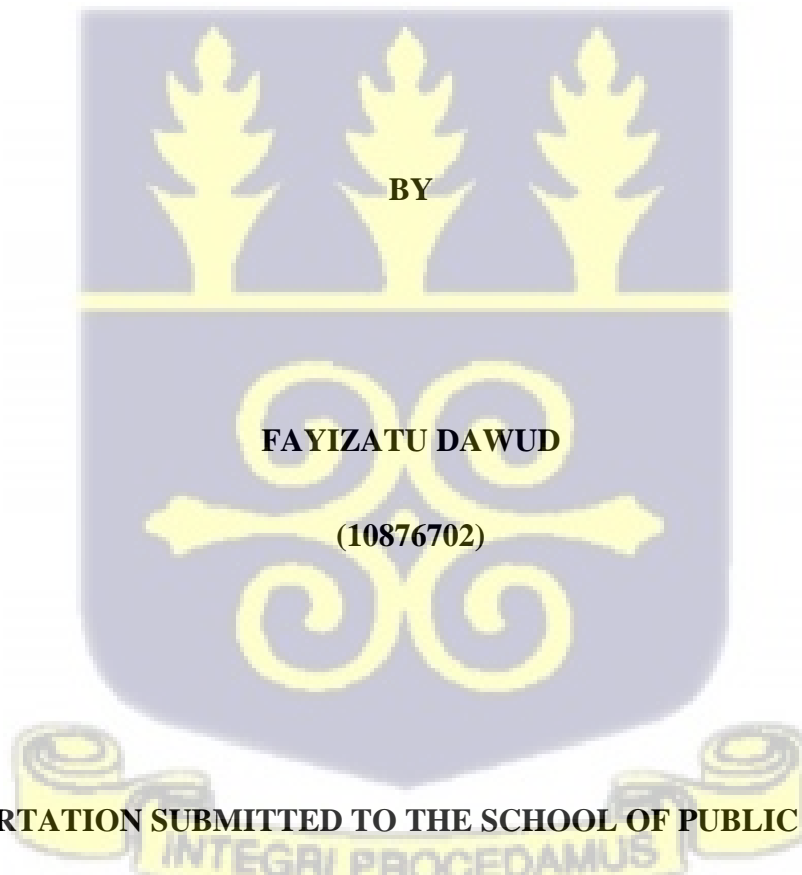


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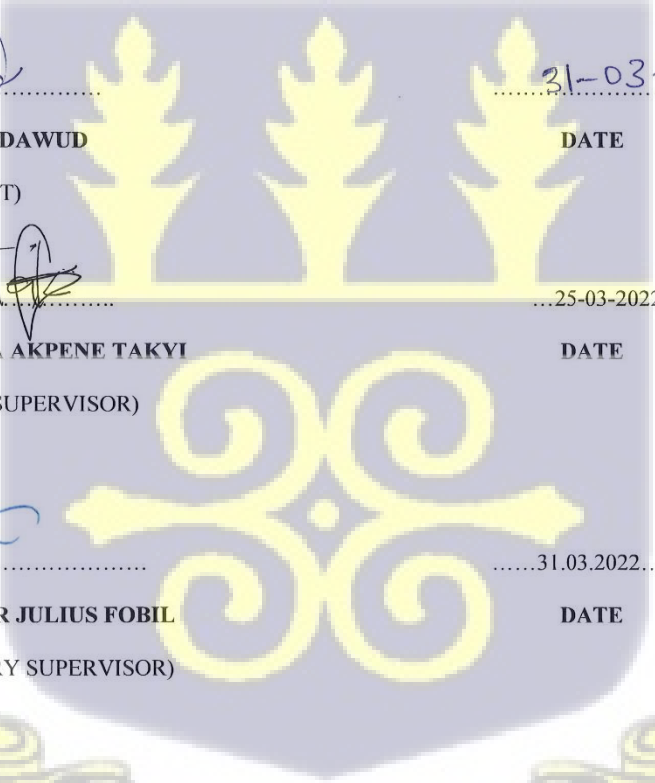
**RELATIONSHIP BETWEEN METAL EXPOSURES, DIETARY MACRONUTRIENT
INTAKE, AND BLOOD GLUCOSE LEVELS OF INFORMAL ELECTRONIC WASTE
RECYCLERS IN GHANA.**



**A DISSERTATION SUBMITTED TO THE SCHOOL OF PUBLIC HEALTH,
UNIVERSITY OF GHANA IN PARTIAL FULFILLMENT FOR THE AWARD OF
MASTER OF SCIENCE (MSc) DEGREE IN OCCUPATIONAL HYGIENE**

DECLARATION

I, Fayizatu Dawud, declare that except for the other people's investigations which have been duly acknowledged, this work is the result of my own original research and that this dissertation, either in whole or in part has not been presented elsewhere for another degree.



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DEDICATION

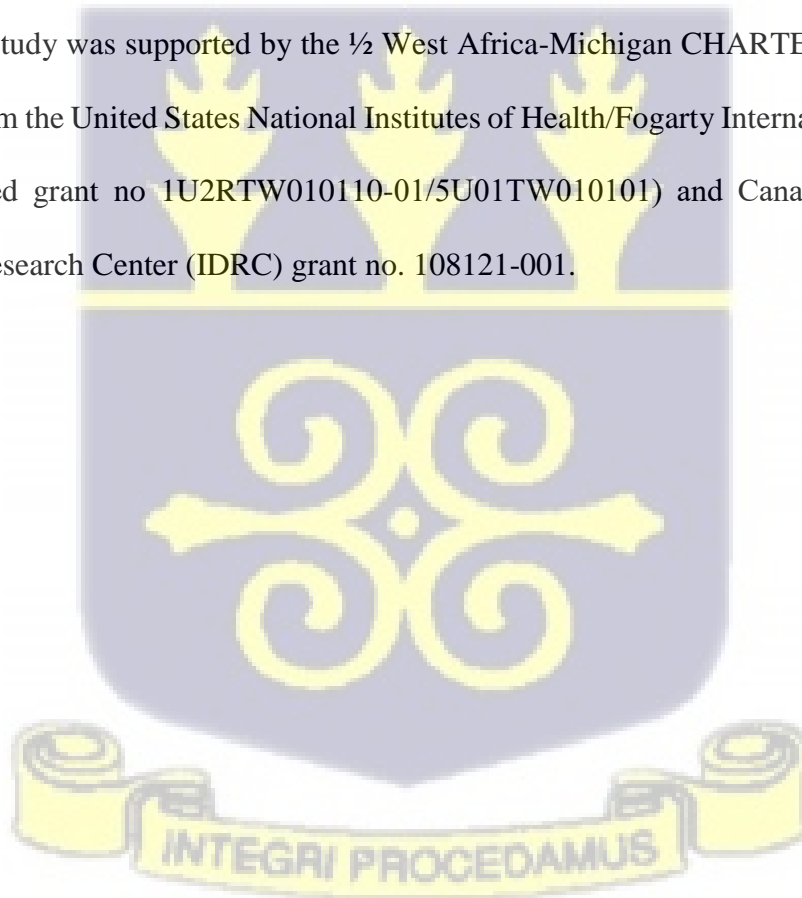
I dedicate this work to my family and friends. A special feeling of gratitude to my loving parents for their prayers and support. My siblings for their encouragement and support throughout the process. To my amazing friends that contributed in diverse ways may Allah strengthen our bond.



ACKNOWLEDGEMENT

Glory be to the Almighty Allah for His grace, guidance, strength, and protection that have enabled me to work on this project successfully. I wish to use this opportunity to express my profound gratitude to my supervisors Professor Julius Fobil, Dr. Arko Mensah, and Dr. Sylvia Akpene Takyi who contributed immensely towards the success of this work. Further appreciation goes to Dr. Godfred Egbi and Mr. Ebenezer Ofori-Attah for supporting the lab analysis at the nutrition department at Noguchi Memorial Institute for Medical Research (NMIMR), University of Ghana.

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ABSTRACT

Background: Exposure to metals such as lead (Pb) and cadmium (Cd) has been linked to metabolic diseases like diabetes. However, the intake of dietary macronutrients (i.e., carbohydrates, proteins, and fats) has been shown to modify metal-induced adverse effects. Although metal exposures are generally high among informal electronic waste (e-waste) recyclers, the joint effect of metals and dietary macronutrients on their metabolic health has not been studied.

Objective: This study investigated the relationship between metal exposures (Pb and Cd), dietary macronutrients intake, and blood glucose levels of e-waste recyclers at Agbogbloshie and a comparison (Madina-Zongo).

Methods: A cross-sectional study involving 100 e-waste recyclers and 51 controls was conducted. Blood levels of Pb and Cd were measured using the Inductively Coupled Plasma Mass Spectrometer (ICPMS; Varian 820MS). Dietary macronutrients intake was evaluated using a 48hr recall. To determine diabetes prevalence, de-identified whole blood samples were analyzed for glycated hemoglobin (HbA1c) levels, using High-Performance Liquid Chromatography (HPLC®). Ordinary least square regression model was used to estimate the joint relationship between metal exposures, dietary macronutrient intake, and blood glucose levels.

Results: Except for proteins intake, both e-waste recyclers and the comparison group did not meet the dietary reference intake (DRI) requirements for dietary carbohydrate, total fats (saturated fat, monounsaturated fat, polyunsaturated fat, OMEGA 3, OMEGA 6, cholesterol), and dietary fiber. Diabetes prevalence was significantly higher in the comparison population (Prev. = 41 %, 95 % CI: 28.41, 55.26 %) than in the recyclers (Prev. = 31.00 %, 95 % CI: 22.63, 40.84 %). Still among both groups, dietary intake of macronutrients like OMEGA 3 and cholesterol was linked to

significant increases in blood glucose levels ($p < 0.05$). Furthermore, when the analysis was limited to recyclers, saturated fat, OMEGA 3, and cholesterol intake was still associated with significant increases in their blood glucose levels ($p < 0.05$). Jointly, while every 1 mg of dietary cholesterol consumed was associated with a 0.7% increase in blood glucose levels (95% CI: 0.001, 0.012; $p = 0.015$), each $1\mu\text{g/L}$ exposure to Pb was linked to a 9% increase in blood glucose levels (95% CI: 0.001, 0.017; $p = 0.025$) among the e-waste recyclers.

Conclusion: Although the dietary consumption of cholesterol and fat was not high, it is still possible that exposure to Pb and Cd, may still increase the risk of diabetes among both e-waste recyclers and the general population.



TABLE OF CONTENT

Table of Contents

DECLARATION	i
DEDICATION	ii
ACKNOWLEDGEMENT	iii
ABSTRACT	iv
LIST OF TABLES	viii
LIST OF FIGURES	x
LIST OF ABBREVIATIONS	xi
CHAPTER ONE	1
1.0 INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement	3
1.3 Conceptual Framework	5
.....	6
1.4 Justification	7
1.5 Objectives	8
CHAPTER TWO	9
2.0 LITERATURE REVIEW	9
2.1 Electronic Waste and informal Recycling	9
2.2 Metal Exposures	10
2.3 Lead (Pb) exposure among e-waste recyclers	11
2.4 Cd exposure among e-waste recyclers	12
2.5 Dietary Macronutrient Intake	14
2.6 Prevalence of diabetes	15
2.7 Association between dietary macronutrient intake and blood glucose levels	16
2.8 Metal exposures and blood glucose control	19
2.9 Relationship between metal exposures, dietary intake, and blood glucose levels	22
CHAPTER THREE	23
3.0 METHODOLOGY	23
3.1 TYPE OF STUDY	23
3.2 VARIABLES OF INTEREST	23

3.3 STUDY POPULATION AND PROCEDURE.....	24
3.4 SAMPLING TECHNIQUE	25
3.5 DATA COLLECTION TECHNIQUES & TOOLS	26
3.6 Analytical Procedures	27
3.6.1 Macronutrient Analysis.....	27
3.6.2 Laboratory Metal Analysis and Quality Control.....	28
3.6.3 Laboratory Analysis of HbA1c and Quality Control Measures	29
3.7 Data Processing and Analysis	31
3.8 Ethical approval and consent to participate	32
CHAPTER FOUR.....	33
4.0 RESULTS	33
4.1 Social-demographic Characteristics of Study Population.....	33
4.2 Metals Exposure.....	33
4.3 Dietary Macronutrients Intake	33
4.4 Prevalence of Diabetes.....	34
4.5 Relationship between metal exposures and blood glucose levels	35
4.6 Association between dietary macronutrient intake and blood glucose levels	36
4.7 Relationship between metal exposures, dietary macronutrient intake and blood glucose levels of e-waste recyclers and comparison group	37
CHAPTER FIVE	41
5.0 DISCUSSION	41
5.1 Dietary macronutrient intake among e-waste recyclers and comparison population.....	41
5.2 Prevalence of diabetes among e-waste recyclers and comparison group.....	42
5.3 Relationship between metal exposures and blood glucose levels	43
5.4 Relationship between dietary macronutrient intake and HbA1c.....	44
5.5 Relationship between metal exposures dietary macronutrient intake and blood glucose levels...	46
CHAPTER SIX.....	48
CONCLUSION.....	48
RECOMMENDATIONS:.....	48
Strengths of the study:	49
Limitations of the study:	49
REFERENCES	50
APPENDICES	82
APPENDIX I	82
APPENDIX II	83

APPENDIX III..... 84
APPENDIX IV..... 85
APPENDIX V..... 86



Table 1. Dietary macronutrient intake of e-waste recyclers and comparison group. 34
Table 2: Prevalence of diabetes among e-waste recyclers and comparison group 35

Table 3: Relationship between metals exposures and blood glucose levels of e-waste recyclers and comparison group..... 35

Table 4a: Association between dietary macronutrient intake and blood glucose levels among e-waste recyclers and comparison group. 36

Table 4b: Relationship between dietary macronutrient intake and blood glucose levels of e-waste recyclers only 37

Table 5a: Relationship between Pb exposures, macronutrient intake and blood glucose levels of e-waste recyclers and comparison group. 39

Table 6a: Relationship between Cd exposure, macronutrient intake and blood glucose levels of e-waste recyclers and comparison group. 40



LIST OF FIGURES

Figure 1: Conceptual Framework displaying the relationship between metal exposures, dietary macronutrient intake and blood glucose levels..... 7

Figure 2: Image of HPLC machine..... 30

Figure 3: Analysis of HbA1c in de-identified whole blood samples..... 30



LIST OF ABBREVIATIONS

Pb – Lead

Cd – Cadmium

PM – Particulate matter

PAH – Polyaromatic Hydrocarbons

EPA – Environmental Protection Agency

EDCs – Endocrine-Disrupting Chemicals

BCAA – Branch-Chained-Amino-Acid

As - Arsenic

PPE – Personal Protective Equipment

MSW – Municipal Solid waste

SWM – Solid Waste Management

BFRs – Brominated Flame Retardants

PCBs – Polychlorinated Biphenyls

CRTs – Cathode Ray Tubes

LCD – Liquid Crystal Display

LED – Light-Emitting Diodes

Cr – Chromium

Ni – Nickel

Hg – Mercury

WHO – World Health Organization

AMDR – Acceptable Macronutrient Distribution Range

DNA – Deoxyribose Nucleic Acid

ROS – Reactive Oxygen Species

T2D – Type 2 Diabetes

NHANES – National Health and Nutrition Examination Survey

Cu – Copper



Zn – Zinc

GLUT4 – Glucose Transporter-4

RNA – Ribose Nucleic Acid

ZnTs – Zinc Transporters

mRNA – Messenger Ribose Nucleic Acid

HPLC – High-Performance Liquid Chromatography

DRI – Dietary Reference Intake

IRB – Institutional Review Board

BMI – Body Mass Index

K₂EDTA – Dipotassium ethylenediaminetetraacetic acid

ICPMS – Inductively Coupled Plasma Mass Spectrometer

HbA1c – Glycated Hemoglobin

BLL – Blood Lead Levels

Poly Fat - Polyunsaturated Fat

Sat Fat – Saturated Fat

Mono Fat – Monounsaturated Fat



CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Diabetes mellitus is a leading cause of death, blindness, and chronic kidney failure all over the world. Diabetes has also been linked to the incidence of several vascular diseases, including myocardial infarction, stroke, and peripheral vascular disorders (Pálsson & Patel, 2014; Sone, 2018; Strain & Paldánius, 2018). Particularly, diabetes mellitus develops owing to reduced insulin sensitivity, and insufficient insulin production. Apart from genetic predisposition, several research works have also identified excessive calorie consumption, obesity, and lack of physical activity as key risk factors for the development of diabetes. For instance, the excessive intake of macronutrients (e.g. carbohydrates, fat, and protein) has been associated with the development of obesity and diabetes mellitus (Kim & Song, 2019; Wali et al., 2021). Practically, the consumption of fat-rich diets may alter insulin secretion and cause an impaired glucose balance (Imamura et al., 2016; Kolb et al., 2018; Sears & Perry, 2015).

Apart from dietary intake, the incidence of diabetes seems to increase in tandem with the exposure to various environmentally hazardous chemicals like metals which also tend to increase with rapid industrial development. Globally, rapid technological progress coupled with rising demand for information technology has resulted in massive volumes of electronic waste (e-waste) (Nti et al., 2020; Srigboh et al., 2016; Takyi et al., 2020, 2021; Wagner, 2009). This waste contains hazardous chemicals, which pose significant harmful environmental impacts if not well disposed or recycled. Particularly in Ghana, the informal techniques such as manual dismantling, and open-air burning employed, unintentionally releases metals (e.g. lead (Pb), cadmium (Cd), etc.), particulates (e.g.

particulate matter (PM)), and organic compounds (e.g. dioxins, Polycyclic Aromatic Hydrocarbons (PAH) into the environment. The US Environmental Protection Agency (EPA) has classified some of the metals associated with informal e-waste recycling as endocrine-disrupting chemicals (EDCs), which have the potential to alter metabolic processes in the body. Exposure to these environmental pollutants induces several pulmonary and cardiovascular health effects when inhaled over time (Gangwar et al., 2019; Jin et al., 2015) For instance, exposure to Pb may induce an increased release of reactive oxygen species (ROS), which impairs the normal function of the pancreatic and Islet cells and further enhances insulin resistance in the body (Ji et al., 2021a; Noh et al., 2021). Such impaired biological processes have been shown to influence blood glucose metabolism and control in humans (Kalyani & Egan, 2013).

Balanced diet, together with or in place of hypoglycemic medications, is an integral way of managing impaired metabolism of blood glucose (Guo et al., 2020; Ley et al., 2014). The consumption of different diets with the varying nutritional content of macronutrients (including fats, carbohydrates, and proteins) may result in changes in metabolites and the gut microbiota, responsible for the entire body's glucose metabolism (Guasch-Ferré et al., 2016). Several amino acid containing-diets, for example, may alter plasma branched-chain-amino-acid (BCAA) concentrations, which are tied to an increased risk of type 2 diabetes (Garcia-Perez et al., 2017). Some diets have been reported to be associated with significant reductions in the effects of chemicals on metabolic diseases like hypertension (Takyi, et al., 2020). For instance, Takyi et al., (2020) reported that iron-rich diets contain both antioxidant and anti-inflammatory properties, which may reduce the effects of oxidative stressors, associated with chemicals exposures, by terminating and inhibiting chain reactions of reactive oxygen species to regulate blood glucose.

However, to better understand the significance of dietary effects on blood glucose control, more research into the effects of diet on glucose metabolism is needed.

Studies investigating the potential modifying effects of diets (macro and micronutrient) intake on environmental pollutant-induced diabetes among groups exposed to environmental pollutants are limited (Hehua et al., 2021; Hwang et al., 2020). The few studies that have examined these relationships, failed to consider informal e-waste recyclers, who are particularly at risk of exposure to a myriad of metals, given the nature of their job. To better understand how diet (macro and micronutrients) can mitigate the negative effects of environmental contaminants on blood glucose, well-designed, rigorous research remains necessary. This study we measured metal (Pb and Cd) levels, as well as HbA1c and dietary macronutrient intake, among waste recyclers at Agbogbloshie and a general population (Madina-Zongo) who are unexposed to e-waste recovery in order to better understand the relationship between balanced diets and blood glucose metabolism. Furthermore, the study investigated the joint association between metal exposures, dietary macronutrient intake among e-waste workers.

1.2 Problem Statement

The presence of toxic metals in the environment is alarming and potentially dangerous to human health (Jaishankar et al., 2014; Tay et al., 2019). This is because, they are abundant in nature and may be found in the air, water, and soil, thus increase the risks of human exposure (Masindi & Muedi, 2018). E-waste recycling in the informal economy is a major source of pollution in some parts of the world. It is worth mentioning that global e-waste volumes have increased significantly

in the last decade, rising by 21% in only five years to 53.6 million tons in 2019 (Forti et al., 2020). Meanwhile, only 17.4% of the e-waste produced in 2019 was formally collected and recycled; implying that precious metals worth \$57 billion were wasted or burned rather than being collected for recycling or reuse (Forti et al., 2020). Agbogbloshie e-waste dump-site in Ghana is one of the biggest in sub-Saharan Africa, which employs young male migrants in search of greener pastures. Regrettably, these recyclers employ cheap and crude methods such as manual dismantling, open-air burning, as well as sorting and collection, which expose them to a myriad of chemicals including dioxin, furans, and fumes of metals (Akormedi et al., 2013; Laskaris et al., 2019; Srigboh et al., 2016). The use of such crude recycling technologies exposes not only the recyclers but also the general population to hazardous chemicals.

Metal exposure and accumulation in the liver and pancreas may affect gluconeogenesis and insulin production in the liver, ultimately leading to the development of diabetes (Buha et al., 2020; Hong et al., 2021; Ji et al., 2021). Some studies have also reported that nutrient (macro and micronutrient) deficiencies or excessive intake, coupled with metal exposures may play an important role in the development of diabetes (Dufault et al., 2015). E-waste recyclers are at a higher risk of developing metabolic disorders like diabetes, hypertension, and other non-communicable diseases, given their high risk of exposure to a myriad of deleterious chemicals. For instance, exposure to Pb has been reported to induce oxidative stress and further promote insulin resistance, thus giving rise to uncontrolled blood glucose levels. In addition, exposure to Cd impairs glucose homeostasis, thus increasing the risk of type 2 diabetes in humans (Buha et al., 2020; Edwards & Ackerman, 2016). Furthermore, the exposure to Cd may also disrupt insulin secretion in the pancreas, leading to risks of diabetes (Buhari et al., 2020; Hong et al., 2021; Ji et al., 2021b) Although nutrition has been

identified to play a mitigating role by reducing the effects of these pollutants on metabolic health, the macronutrient status of these e-waste recyclers is not known. A study reported by Takyi et al. (2021) found a poor micronutrient intake among recyclers at Agbogbloshie. Unhealthy eating pattern is a key component in the development of diabetes, yet the macronutrient status of e-waste recyclers is not well studied. Considering the rigorous and physically demanding nature of informal e-waste recycling activities, human exposure to these metals as a source of micronutrients depletion may occur (Park JK et al., 2017; Takyi et al., 2020; Wittsiepe et al., 2017), thus predisposing these recyclers to poor nutritional and blood glucose status. Consequently, this study investigated the joint relationship between metal exposures, dietary intake, and blood glucose levels among e-waste recyclers at the Agbogbloshie and a comparison group at Madina-Zongo.

1.3 Conceptual Framework

As shown in figure 1 below, informal waste recycling consists of manual processes such as collecting, sorting, burning and dismantling to retrieve metals such as copper (Akormedi et al., 2013). Tools such as hammers, spanners and chisels are used in the dismantling process (Akormedi et al., 2013). These manual activities release metals such as Pb and Cd into the environment. Exposure to these metals causes oxidative stress, which in turn releases reactive oxygen species (ROS). Although dietary macronutrients are known to ameliorate the effects of metal exposures, high intake of macronutrients can promote oxidative stress, that is, a high intake of dietary carbohydrates and animal-based proteins and excessive fats contributes to the long-term consequences of nutritionally mediated inflammation, which induces the release of ROS. The increase production of ROS impairs pancreatic cell, insulin resistance and islet cell dysfunction hence affecting both insulin secretion and action; thus, leading to a rise in blood glucose levels.

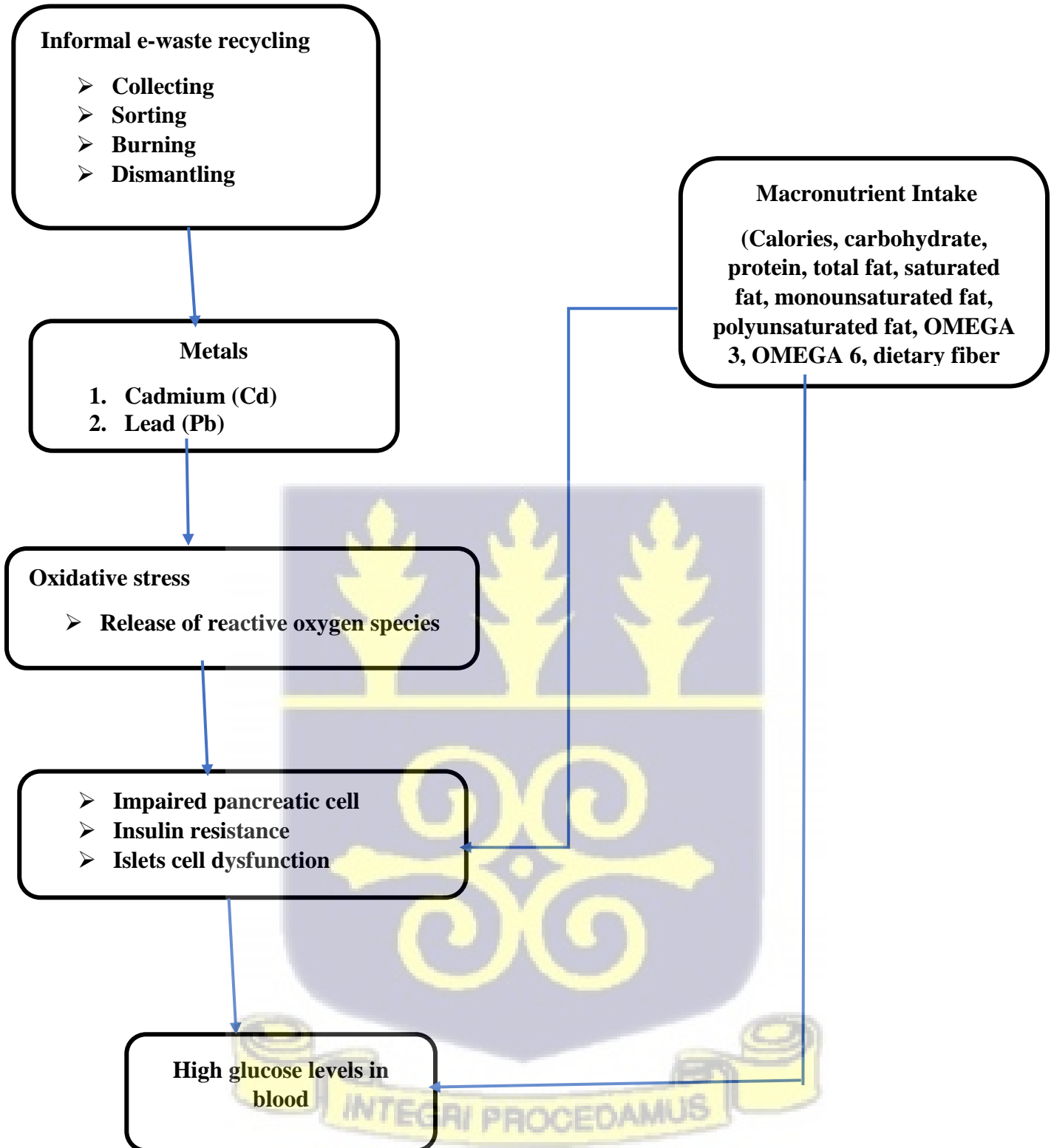


Figure 1: Conceptual Framework displaying the relationship between metal exposures, dietary macronutrient intake and blood glucose levels.

1.4 Justification

Electronic waste recycling at Agbogbloshie involves manual dismantling and open-air burning to retrieve valuable parts. These activities, which release very toxic chemicals into the environment and are not regulated are noted for causing burns as well as pollute the air, water, soil and tend to expose recyclers to the hazardous chemicals like metals, dioxins, toxins, furans, and fumes of metals (Akormedi et al., 2013; Heacock et al., 2018; Wittsiepe et al., 2015). More hazardous chemicals are likely to be released into the environment, given the increasingly huge volumes of this waste shipped into the country. Although occasionally trained by organizations like the Blacksmith Institute and Green Earth Ghana on using cleaner technologies in recycling such waste, recyclers at Agbogbloshie continue to use the rudimentary methods and are therefore still exposed to several pollutants. This is because the recyclers solidly believe that the use of crude methods like open-air burning and manual dismantling are cost-effective and convenient. Despite these intense exposures and associated health effects, the likely associations between these metal exposures, macronutrient status, and their effects on blood glucose control have received little attention. As probable, the metabolic health of occupationally exposed groups such as e-waste recyclers may be primarily affected by sheer exposure to these metals at poor macronutrient status. With all the exposures described, the e-waste recyclers are rarely trained on safe and appropriate procedures to follow safety measures or use personal protective equipment (PPE) when performing recycling activities, thus putting both their lives and those of the members of the general population at risk of several chronic diseases like diabetes and hypertension.

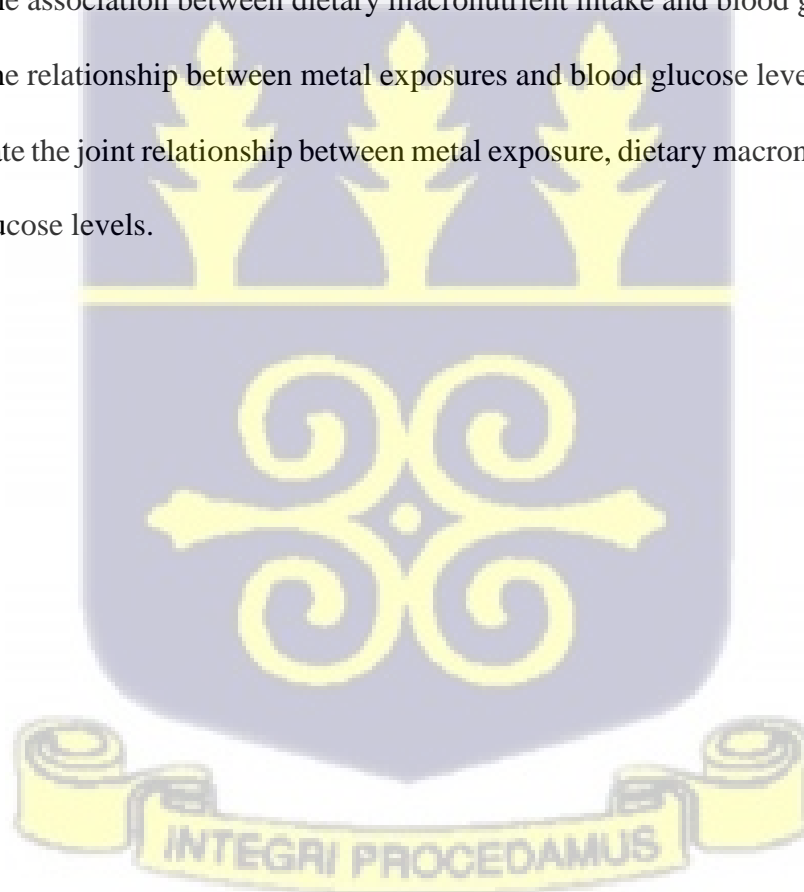
1.5 Objectives

1.5.1 General Objectives

Investigate the relationship between metal exposure, dietary macronutrient intake, and blood glucose levels of informal e-waste recyclers at Agbogbloshie and a comparison group in Ghana

1.5.2 Specific Objectives

- Estimate and compare dietary macronutrient intake of e-waste recyclers and a comparison group
- Measure and compare blood glucose levels
- Assess the association between dietary macronutrient intake and blood glucose levels
- Assess the relationship between metal exposures and blood glucose levels
- Investigate the joint relationship between metal exposure, dietary macronutrient intake, and blood glucose levels.



CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Electronic Waste and informal Recycling

E-waste management issues have been exacerbated by rapid modernization, industrialization, and consumer demand for better products. Regrettably, the lifespan of digital technology products like computers, television, among others, has decreased from 5–10 years to 3–4 years, given such equipment are designed to be replaced rather than repaired (Agamuthu et al., 2015). Poor communities in developing nations, however, can only afford second-hand versions of electrical and electronic equipment (EEE).

Despite the Global North's building rules and infrastructure to recycle e-waste, shipping it to the Global South, where there are no policies or legislation to govern its handling, remains profitable (Daum et al., 2017). Receiving countries including developing nations often lack policies, awareness, and waste handlers; hence, employ crude methods of recycling like open-air burning and dismantling. Regrettably, apart from the e-waste recyclers who employ rudimentary methods and lack suitable tools, the general population who live near informal recycling dumpsites, children, and pregnant women are also affected and vulnerable groups (Bakhiyi et al., 2018; Srigboh et al., 2016).

These unregulated recycling activities performed in developing nations, which uses manual methods to retrieve precious metals present in e-waste, pollutes the environment through acid leaching and open burning, making landfills and dumpsites the most polluted areas (Tetteh &

Lengel, 2017; Velis, 2017). Agbogbloshie in Ghana, is one of the world's largest landfills, covering over 20 acres, that allows for both crude and manual recycling, it collects about 15% of worldwide e-waste for informal recycling, discharging lead, mercury, and zinc into the ecosystem, making the site very poisonous (Maphosa & Maphosa, 2020). According to (Yu et al., 2017), most African recyclers lacked recycling facilities and had to rely on dismantling, burning, and acid leaching to recover valuable metals. Studies by (Oteng-Ababio, 2012) stated that recyclers resorted to physical and labor-intensive techniques to recover valuable metals in e-waste; this was backed up by Peluola, (2016) who noticed that recyclers resorted to dismantling and leaching of precious metals. The Agbogbloshie in Ghana is one of the world's most contaminated places, where precious metals are recovered using primitive and unsophisticated methods such as hand disassembling and burning (Kyeremeh et al., 2018). According to Schroeder et al., (2019), over 95 percent of e-waste was handled in slums without the use of protective equipment, exposing recyclers to hazardous chemicals. Orisakwe et al., (2020) confirmed these findings, suggesting that e-waste posed human health and environmental dangers in Africa due to a lack of legislation and infrastructure for recycling and disposal.

2.2 Metal Exposures

Metals are defined as any metallic chemical that is naturally occurring and an element of high atomic weight and with a density five times higher than water as well as possess a relatively high density and hazardous or dangerous at low doses (Tchounwou et al., 2012). These metals including lead, arsenic, cadmium, chromium, mercury, nickel etc are naturally occurring due to their existence in the earth's crust. Explicitly, after the end-life of these electronic equipments, informal e-waste recyclers process them to recover valuable materials like copper wires (Perkins et al.,

2014; Srigboh et al., 2016; Takyi et al., 2021). This unintentionally leads to the release of myriad of chemicals including metals like lead, arsenic, cadmium into various media in the environment (Tchounwou et al., 2012). These reported levels are believed to pose several deleterious effects to man, depending on the type of compounds, concentration of compounds, and period of exposure (Vetrivel & Kalpana Devi, 2012).

2.3 Lead (Pb) exposure among e-waste recyclers

Several studies report that Pb exposure may induce oxidative stress and particularly an imbalance between the production of free radicals and the production of antioxidants to detoxify or repair the reactive intermediates (Hu et al., 2020; Lobo et al., 2010; Pizzino et al., 2017). Lead (Pb) toxicity to the major part of human body organs and interferes with metabolism and cellular functions (Martinez-Finley et al., 2012). The most common exposure route for lead is workplace exposure, through water, paint, and ingestion of lead-contaminated foods (Latif Wani et al., 2015). In age-related disorders, a linear connection has been established between blood Pb levels and renal failure. This is due to repeated Pb exposure (Satarug et al., 2020), which has a negative effect on antioxidant pathways (Yabe et al., 2012).

Among adolescents and children in Montevideo-Uruguay, burning cables was identified as the only source of lead exposure in 28.9 % of the sample (Pascale et al., 2016). Other causes of lead exposure identified included gathering of metals (63.8 %), landfills (2.9 %), and paint (4.4 %) (Pascale et al., 2016). This and other similar international studies revealed that blood Pb levels are significantly higher among children exposed to e-waste recycling living in urban environments than those living in rural areas (Guo et al., 2014; Parvez et al., 2021; Zhang et al., 2020).

Additionally, the most commonly reported additional form of lead exposure was manual metal collecting; however, there was no significant link between this form of exposure and high blood Pb levels. Although only a small percentage of the sample had increased exposure to lead in paint, it was found to be strongly linked with increases in blood Pb levels (O'Connor et al., 2018).

Studies carried out in Agbogbloshie by Srighoh et al., (2016), Wittsiepe et al., (2017), and Takyi et al., (2021) reported higher blood Pb levels among e-waste recyclers to be 79.3 mg/L, 92.4 mg/L, and 101.9 mg/L respectively, which was above U.S. CDC/NIOSH reference level of 50 mg/L (5 mg/dL). Furthermore, Amankwaa et al., (2017) also measured higher blood Pb levels among 128 females at the Agbogbloshie e-waste recycling site. The mean blood Pb levels (3.54 g/dL) of non-e-waste recyclers was slightly higher than e-waste recyclers' (3.49 g/dL), but e-waste recyclers' blood Pb levels were higher (0.50–18.80 g/dL) than non-e-waste recyclers' (0.30–8.20 g/dL). Further in Ghana, elevated blood levels of Pb was measured among 12% of e-waste recyclers who burnt e-waste. These findings may seem to suggest that the increasing tons of e-waste shipped into and recycling in Ghana may exposed recyclers and the general population to increasing levels of Pb.

2.4 Cd exposure among e-waste recyclers

Cadmium (Cd) is a very hazardous metal that occurs naturally in the environment and is emitted mostly from industrial sources including mining and metal smelting (Du et al., 2020). Many studies have been carried out to assess the environmental danger of Cd pollution and to undertake human health assessments, resulting in effective Cd exposure reduction (Yao et al., 2020). Dietary intake

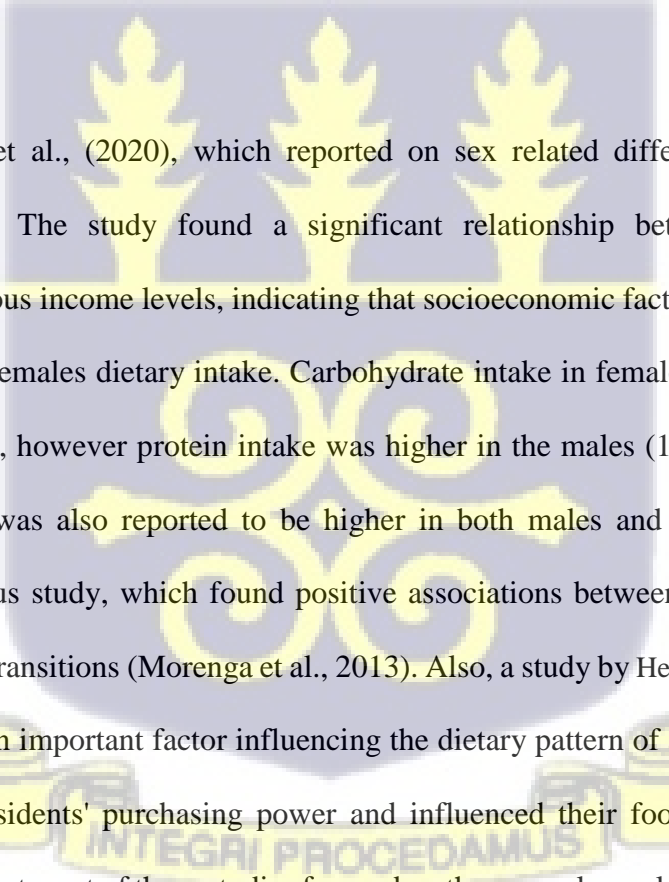
has been recognized as the major pathway in most previous studies (Chanpiwat et al., 2019; Chen et al., 2018), other exposure routes are air pollution, smoking, and occupational activities (Chen et al., 2021; Tapsell, 2017). High levels of Cd have been linked to liver, cardiovascular, and endocrine system damage (Fittipaldi et al., 2019; Gao et al., 2018), as well as renal cancer, which is considered the most sensitive target organ for Cd (Fittipaldi et al., 2019; Gao et al., 2018). Although the mechanisms by which cadmium influences diabetes risk association are not clear, various studies have found a positive association between elevated cadmium levels and type 2 diabetes (Satarug et al., 2017; Tinkov et al., 2018).

Several studies have also looked at Cd exposure in the environment and among e-waste recyclers. In a study investigated by Alli, (2015), among 64 occupationally exposed individuals with a year experience and 56 unexposed group reported a significant increase in blood Cd for the occupationally exposed group than the unexposed, mean B-Cd ($11.63 \pm 1.73 \mu\text{g/dL}$) and ($2.03 \pm 0.55 \mu\text{g/dL}$) respectively. They also indicated that the spray painters and battery chargers among the occupationally exposed had the highest mean B-Cd levels to be $12.85 \pm 1.45 \mu\text{g/dL}$ (Alli, 2015).

Spanning from 2016 till date, various metal exposure assessment studies have been conducted at Agbogbloshie. These studies reported varied results between e-waste recyclers and the comparison group. While Srigboh et al., (2016) measured significantly higher mean levels of Cd ($1.7 \mu\text{g/L}$) among e-waste recyclers, authors like Wittsiepe et al., (2017) and Takyi et al. (2021) contrarily measured higher Cd levels ($0.57 \mu\text{g/L}$ and $0.93 \mu\text{g/L}$ respectively) among their controls.

2.5 Dietary Macronutrient Intake

Macronutrients such as carbohydrates, proteins, and fats are all essential for good health, development, reproduction, and immunity. Poor nutritional diet is a major source of morbidity and mortality, while a certain amount of essential nutrients is required for general wellbeing, deficiencies or excessive amounts of some of these nutrients might have adverse health effects, as well as be a major risk factor for non-communicable diseases (NCDs) such diabetes, cardiovascular diseases, cancers etc (Murray, 2010). Dietary Reference Intake (DRI) can be achieved with a well-balanced diet. Reduction in calorie intake leads to a reduced intake of other nutrients resulting in nutrient deficits.



In a study by Zhao et al., (2020), which reported on sex related differences in energy and macronutrient intake. The study found a significant relationship between dietary energy consumption and various income levels, indicating that socioeconomic factors may have different effects on males and females dietary intake. Carbohydrate intake in females was higher (50.7%) than in males (49.9%), however protein intake was higher in the males (13.4%) than in females (13.1%). Dietary fat was also reported to be higher in both males and females and this was compared to a previous study, which found positive associations between fat intake, economic growth, and nutrition transitions (Morenga et al., 2013). Also, a study by Herforth & Ahmed, (2015), identified income as an important factor influencing the dietary pattern of adults in China, which could have altered residents' purchasing power and influenced their food choices (Herforth & Ahmed, 2015). Given that most of these studies focused on the general population and gender-based studies, literature focused on the micronutrient intake of e-waste recyclers reported by Takyi et al., (2020) stated that e-waste recyclers and the control group did not consume adequate diets rich in

Mg, Ca, Se and Cu which resulted in the lower mean dietary intakes of Se, Ca and Mg among the e-waste recyclers and lower mean dietary intake of Zn among the control group. This is a critical base for my study; thus, the current study will fill the knowledge gap by reporting on the dietary macronutrient intake among toxicant-exposed groups like e-waste recyclers in Ghana.

2.6 Prevalence of diabetes

Several studies have reported on the prevalence of diabetes among adult males in Ghana and elsewhere. However, to the best of my knowledge, no study has investigated the prevalence of diabetes among toxicant exposed groups even though chemical exposures (e.g. Cd, Pb and As) are known to induce the incidence of metabolic diseases like diabetes Cd, and As. The prevalence of diabetes among Ghanaian adults reported in 2019 was 6.46% (Asamoah-Boaheng et al., 2019), 13.9% prevalence in Kumasi in the Ashanti Region (Sarfo-Kantanka et al., 2014) and 9.3% prevalence of diabetes in Accra in the Greater Accra Region (Amoah et al., 2002). In china Von 2019 also found prevalence of diabetes to be 14.2% among adult men (von Euler et al., 2019), 2019). Also, a study conducted by Meo et al., (2019) among men in the Middle East recorded higher prevalence of diabetes among men in Saudi Arabia, UAE, Kuwait and Bahrain to be 29.10%, 25.83%, 25.40%, and 33.60% respectively. All this prevalence had sociodemographic characteristics such as age, daily income, sex and many others play a role in its high prevalence. Given most of these studies focused on the general population, the current study will fill the knowledge gap by reporting the prevalence of diabetes among toxicant-exposed groups like e-waste recyclers in Ghana.

2.7 Association between dietary macronutrient intake and blood glucose levels

Nutrition is the most modifiable factor that may help ameliorate the rising prevalence of metabolic diseases such as diabetes. To better understand diabetes onset, one must first comprehend the physiological processes that occur during and after a meal. Food is digested and absorbed into the bloodstream, where nutrients such as proteins, fats, and carbohydrates are absorbed. Next, glucose, (a type of carbohydrate), causes the endocrine pancreas to produce the hormone insulin. Insulin causes practically all tissue types in the body to absorb and store glucose, particularly the liver, muscle, and fat tissues (Röder et al., 2016).

The major dietary macronutrients are carbohydrates, protein, and fat. The World Health Organization (WHO) recommends getting 55–75 percent of your daily energy from carbohydrates, 10–15 percent from protein, and 15–30 percent from fat (Venn, 2020), while the acceptable macronutrient distribution range (AMDR) for the United States is 10–35 percent protein, 20–35 percent fat, and 45–65 percent carbohydrate (Raubenheimer et al., 2015). All three macronutrients (or at least certain sub-types) have been related to insulin resistance and diabetes (Kroemer et al., 2018). Several studies have examined the relationship between dietary habits and the incidence of diabetes among the general population (Beigrezaei et al., 2019; Erber et al., 2010) but not the case of e-waste recyclers, who are highly exposed to a myriad of chemicals associated with informal e-waste recycling. Other studies have highlighted that dietary factors play a role in the development of glucose intolerance (Russell et al., 2016; Zhang & Ning, 2011). High dietary glycemic index and load, poor dietary fiber, carbohydrate-rich foods (Augustin et al., 2015; Sluijs et al., 2011), excessive calorie consumption and high fat intake (especially saturated fats) (von Frankenberg et al., 2017) can all contribute to glucose intolerance. Contrastingly, high intake of fish (Nanri et al.,

2011), potatoes, vegetables, legumes, and vitamin C (Cooper et al., 2012), are inversely related to the development of type 2 diabetes. Furthermore, the consumption of processed red meat has been linked to an increased risk of insulin resistance and type 2 diabetes (Barnard et al., 2014). In a Health Care professionals Follow-up Study, a high diet of low-fat dairy or skimmed milk products was documented; but not whole milk (Zhang et al., 2021). These findings were linked to a lower incidence of insulin resistance and diabetes in men (Zhang et al., 2021).

Carbohydrate is the most prevalent macronutrient in the human diet, accounting for 45–70% of daily calorie intake (Ludwig et al., 2018; Venn, 2020). While not considered an essential nutrient for humans, their increased intake has lately been linked to carbotoxicity (Kroemer et al., 2018). It has been reported in several human trials that reducing carbohydrate consumption is important for metabolic health, and ketogenic diets severely limit carbohydrate intake to less than 10 percent energy daily, which is effective in weight loss and improving the glycemic profile in type 2 diabetes (Feinman et al., 2015). The molecular effects of carbohydrate intake are thought to be mediated by a variety of pathways. The rapid digestion of simple carbohydrates causes an increase in insulin release, resulting in a decline in blood glucose levels and appetite stimulation (Kroemer et al., 2018). Furthermore, carbohydrate-induced insulin release may induce fat accumulation by increasing lipogenesis and preventing lipolysis (Ludwig et al., 2018). Reactive oxygen species (ROS) is generated when there is a reaction between the ketone of carbohydrate molecule and that of a free hydroxyl group of lipids or amino group of lysine proteins or DNA bases (Lustig, 2013). Increased production of ROS has been linked to insulin resistance and pancreatic beta-cell dysfunction in diabetes (Kaneto et al., 2010).

Fatty acids, despite their poor connotation, are essential for life, playing an essential role in membrane structure and function, cell signaling, steroid hormone synthesis, metabolism, and

energy production. It's biologically probable that high-fat diets cause weight gain, which leads to insulin resistance. This viewpoint is backed up by a significant amount of evidence that obesity is a major contributor to the development of diabetes (Bhupathiraju & Hu, 2016; Wali et al., 2021). This means that any dietary element that leads to weight increase will almost certainly lead to diabetes. The role fat plays in metabolism, energy and fat balance, cell membrane structure and function, and its role as a ligand for nuclear receptor influencing gene expression, makes it highly likely that both the total amount and type of dietary fat play a role in insulin action, weight maintenance, and diabetes prevention (Figueiredo et al., 2017).

Proteins also form an integral functional and structural component of the human systems. Dietary and body proteins differ significantly in chemical composition and physical structure. All proteins are made up of amino acid chains with the required amino nitrogen group. In addition to their role in the body's many protein structures, amino acids serve as precursors for a variety of coenzymes, hormones, and nucleic acids. Their residues are used for energy in the tricarboxylic acid cycle after deamination because of the presence of carbon, oxygen, and hydrogen in the amino acids. A protein-rich diet (defined as 30% of calories) may not always reduce HbA1c, yet it does seem to improve one or more cardiovascular risk factors (Wheeler et al., 2012). Although a high protein diet intake may not necessarily result in weight loss, it does have the potential to reduce diabetes risk through weight loss in some circumstances. For instance, Ke et al., (2018) found that the relationship between protein intake and type 2 diabetes varies depending on type of diet, even though dietary trends may interact with protein intake, dietary patterns should be taken into account when recommending protein consumption for diabetes prevention.

Individual nutrients or foods, are likely to account for dietary effect on glucose metabolism. Consequently, dietary pattern analysis has recently emerged as a new and supplementary method of investigating the link between food and the risk of chronic diseases (Schulz et al., 2021; Zhang et al., 2018).

2.8 Metal exposures and blood glucose control

Diabetes mellitus is a group of metabolic disorders defined by excessive blood sugar (glucose) levels caused by insulin shortage, insulin ineffectiveness, or a combination of these factors (Diabetes, 2013). Diabetes has been associated with vascular diseases and classified as “a form of cardiovascular disease” by the American Heart Association (Bril & Cusi, 2017). With diabetes, insulin is required to transport glucose from the bloodstream into the majority of body cells. In the absence of insulin, only the brain and central nervous system cells can consume glucose from the blood, whereas most body cells utilize molecules other than glucose for energy in the absence of insulin. However, fat metabolism in the absence of glucose metabolism produces toxic ketone molecules, and their accumulation is linked to hyperglycemic coma (Baffy et al., 2012; Sears & Perry, 2015). Further, unmetabolized glucose builds up in the blood, given the inadequacy of insulin in the body. When the renal glucose threshold (10 mmol/L) is exceeded, water is taken from body cells by osmosis to dilute the extremely concentrated blood, subsequently, this glucose is expelled with an inception of dehydration (Gerich, 2010). Diabetes complications cause a significant amount of morbidity and mortality. Hypo- and hyperglycemic coma, as well as infections, are among the acute consequences of diabetes. Microvascular problems such as retinopathy and nephropathy, as well as macro-vascular complications such as heart disease and stroke, are examples of chronic complications associated with diabetes. Risk factors of diabetes further span

from dietary intake, genetics, insulin sensitivity, physical activities, other comorbidities as well as environmental exposures to toxicants.

Metal deposition in the liver and pancreas may modify gluconeogenesis in the liver and impair insulin production, eventually increasing diabetes incidence. Several plausible hypotheses have resulted from studies investigating the relationship between metal exposures and diabetes. Metal exposures have been shown to induce oxidative stress in human (International, 2020; Jan et al., 2015). Primarily, the release of oxidative stressors associated with metal exposures can directly damage pancreatic beta cells, resulting in elevated serum glucose levels (Gerber & Rutter, 2017; Ji et al., 2021). By lowering insulin release, weakening insulin receptors, altering glucose absorption, increasing hepatic gluconeogenesis and pancreatic glucagon production, and decreasing peripheral glucose usage, oxidative stress can cause the elevation of blood glucose levels (Khan & Awan, 2014; Sharma et al., 2014). Other authors also highlight that the islet β -cells have a high expression of metal transporters but a low expression of antioxidants, resulting in a weak anti-oxidative defense system in pancreatic islet cells, making the islet cells extremely sensitive to the effects of metals, resulting in pancreatic islet β -cell dysfunction, destruction, or even death (Bensellam et al., 2021; Miki et al., 2018; Velayutham et al., 2018). Moreover, metals have also been shown to influence a variety of molecules, including glucose transporter type 4, nuclear factor kappa B, mitogen-activated protein kinases, and phosphoinositide 3-kinase, all of which are involved in insulin signaling, increasing the risk of diabetes (Ji et al., 2021).

The exposure to arsenic (As) may disrupt insulin production and secretion in pancreatic cells, thus reduce glucose absorption in insulin sensitive cells (Castriota et al., 2020; Fu et al., 2010). Furthermore, among Chinese residents, insulin secretion was lower in the group exposed to Cd for

more than 10 years than in the group exposed to Cd for less than 10 years (Hong et al., 2021; Son et al., 2015). Other studies also found that, the accumulation of Cd is linked to cell degeneration or necrosis, as well as weak degranulation in pancreatic cell (Edwards & Ackerman, 2016; Zheng et al., 2008). As a result, Cd exposure may be the cause of diabetes symptoms by causing islet cell disintegration and oxidative stress (Edwards & Ackerman, 2016). Cadmium (Cd) may affect the glucose transporter (Mirzaei et al., 2020) thyroxine transformation and greater levels for the death of glands such as pancreatic cells in diabetes (Khan & Awan, 2014). Due to similar chemical characteristics, Cd has the potential to replace zinc (Zn) (Buha et al., 2017). Cadmium (Cd) therefore binds to Zn transporters with a high affinity, and this adversely affect the islet cells (Muayed et al., 2012).

Lead (Pb) has been cited to toxic to several human organs, as it interferes with metabolism and cellular functions in the body (Martinez-Finley et al., 2012). For instance, high Pb exposure was related to the yearly increases in fasting blood glucose (Ji et al., 2021). Furthermore, age-related disorders, a linear relationship was observed between blood Pb levels and renal failure, owing to their repeated Pb exposure (Satarug et al., 2020) which has a negative effect on antioxidant pathways (Yabe et al., 2012).

Metal induced toxicity may disrupt antioxidant mechanisms, bind to a variety of biological proteins, changing their kinetics and, as a result, their function which causes direct damage to pancreatic cells by producing reactive oxygen species (ROS), a major source of oxygen level imbalance (Khan & Awan, 2014) and reduces the gene's ability to enhance activity and regulate mRNA in pancreatic cells, decreasing insulin synthesis. Protein nucleic acid, and lipid peroxidation may be harmed as a result of this antioxidant imbalance. The development of several

human diseases, including diabetes, is linked to the oxidative attack of cellular components by ROS (Matough et al., 2012; Schmidt et al., 2010). Essential metals play an important function in biological systems. They protect the structural integrity of proteins by regulating redox systems, binding to enzymes as cofactors (Chitturi et al., 2015). Metals imitate the activity of essential metals by competing with them for enzymatic binding as cofactors, resulting in tissue damage.

Furthermore, exposure to metals has been linked to an increase in body weight, according to population research. Exposure to metals may be linked to diabetes since weight increase is a recognized risk factor (Faulk et al., 2014; Ji et al., 2021; Nie et al., 2016). Based on these findings, several investigations on the association between metal exposure and diabetes have been conducted. They however, did provide inconclusive findings (Borné et al., 2014; Feng et al., 2015; Hansen et al., 2017; Menke et al., 2016) As a result, it may be concluded that a direct link between metals and diabetes has yet to be established. Even if such a relationship exists, it is relatively weak. Likewise, prior epidemiologic research that reported inconclusive results linking metals and diabetes had limitations. The current study aims to investigate the association between metal exposures and diabetes incidence especially among toxicant exposed groups like informal sector e-waste recycling in Ghana.

2.9 Relationship between metal exposures, dietary intake, and blood glucose levels

To the best of my knowledge and critical search and review of literature, the joint relationship between metal exposures, dietary macronutrient intake and diabetes incidence research is very scant. Following this, the current research will focus on providing baseline evidence on the joint relationship between metal exposures associated with informal e-waste recycling as well as dietary macronutrient intake and blood glucose levels among e-waste recyclers in Ghana.

CHAPTER THREE

3.0 METHODOLOGY

3.1 TYPE OF STUDY

In this study we obtained and analyzed archived samples (blood and urine) that were collected during GEOHealth II project (a longitudinal study with 3 reported rounds of data collection) for levels of glucose metabolism (glycated hemoglobin) and metals - lead (Pb) and Cadmium (Cd). For purposes of the study, we retrieved and analyzed blood samples from round 1 only, generated data on levels of glycated hemoglobin and concentration of metals in blood in a cross-sectional design. We also obtained dietary information and nutritional status of the participants (e-waste recyclers and comparison group) to analyze and study the relationship between metal exposures (Pb and Cd), dietary macronutrient intake and blood glucose levels of informal e-waste recyclers at Agbogbloshie and a comparison group (Madina).

3.2 VARIABLES OF INTEREST

3.2.1 Dependent variable

The dependent variable for this study was the blood glucose (HbA1c) levels of the e-waste recyclers and the comparison population.

3.2.2 Independent variable

The independent variables for this study were the exposure to metals (Pb and Cd) and dietary macronutrient (total calories, carbohydrates, protein, total fat, saturate fat, polyunsaturated fat, monounsaturated fat, OMEGA 3, OMEGA 6, dietary fiber and cholesterol) intake.

3.3 STUDY POPULATION AND PROCEDURE

The sample size was predetermined by the parent project (GEOHealth II project). A total of 132 study participants were recruited during the GEOHealth II project (a longitudinal study with 3 reported rounds of data collection). Given the fore knowledge of a likely 10-20 percent attrition as indicated in literature for cohort studies, the broader project recruited; 100 recyclers and 50 participants for the comparison population at baseline (Nti et al., 2020; Takyi et al., 2020, so a total of 150 samples was analyzed.

100 of which are Agbogbloshie waste recyclers assigned to different job task at the site and 50 controls from Madina-Zongo which was approximately 18km from Agbogbloshie. The reference population at Madina-Zongo were selected as control for the exposed population at Agbogbloshie in order to better characterize health effects associated with informal e-waste recycling. Apart from whether or not participants participate in e-waste recycling, these two communities have similar demographic characteristics, such that residents are mostly from Ghana's northern regions, are mostly Moslems, and eat similar foods.

3.4 SAMPLING TECHNIQUE

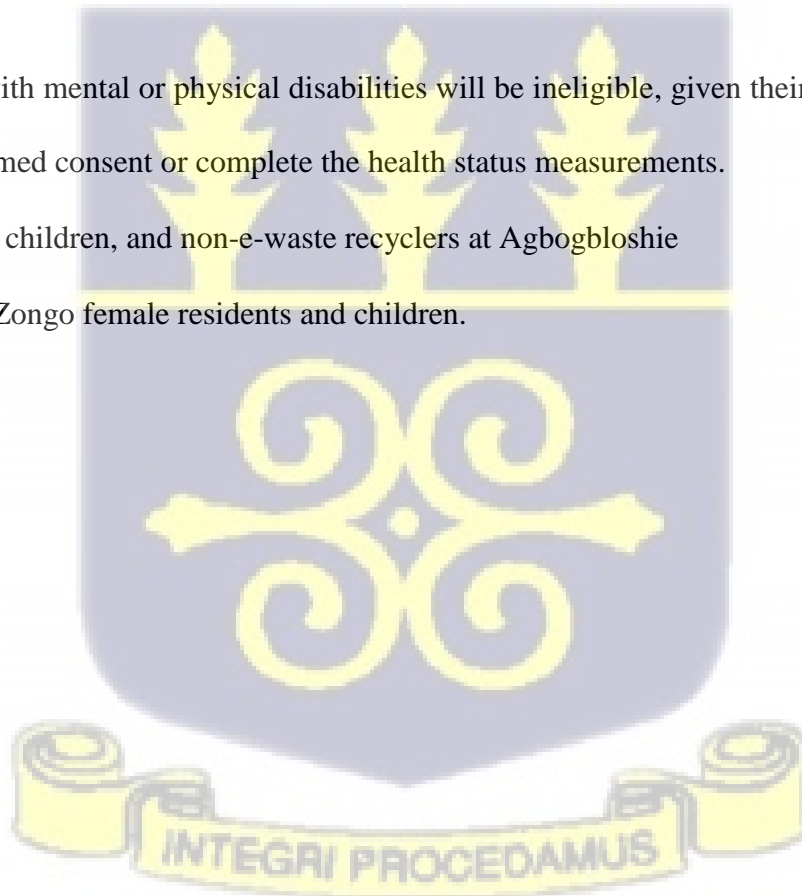
1 Inclusion and Exclusion Criteria:

3.4.1 Inclusion

- Adult males aged 18 to 50 years and above who had worked at the e-waste site for at least six months
- Participants must be of sound mind to be included.
- The comparison group consisted of male inhabitant aged 18 to 50 years who had lived in Madina-Zongo for at least six months but not been exposed to e-waste recovery.

3.4.2 Exclusion

- People with mental or physical disabilities will be ineligible, given their inability to grasp the informed consent or complete the health status measurements.
- Females, children, and non-e-waste recyclers at Agboglobshie
- Madina-Zongo female residents and children.



3.5 DATA COLLECTION TECHNIQUES & TOOLS

3.5.1 Anthropometric Measurements

Secondary data on weight, height and calculated body mass index (BMI), was drawn from the GEOHealth II Project, as already published by Takyi, et al., (2020). Briefly, a standardized protocol was used to measure the participants' height and weight. Using a Seca stadiometer (Seca; Germany), the participant's height was corrected to the nearest 0.1 cm by standing upright on a flat surface without shoes and pressing the back of the heels and the occiput against the stadiometer (Alkhajah et al., 2012; Peprah, 2014; Zeba et al., 2022). Furthermore, using a portable Seca scale, participants' body weight was measured to the nearest 0.1 kg (Seca 770; Hamburg, Germany). Both study sites used the same model of standard calibrated balance. Participants' BMI was calculated by multiplying their weight in kilograms (kg) by their height in meters squared (m²)

3.5.2 Dietary Intake assessment

Information on the dietary macronutrient status of participants (e-waste recyclers and comparison group) was obtained from the larger project (GEOHealth II project) field data collection. Each participant's daily dietary macronutrient intake was documented using a semi-structured 48-hour dietary recall guide. This recall was conducted twice (a 24-hour recall on each day) to assess the individual's day-to-day variability due to the variety of foods consumed on different days. To ensure consistency in the survey method across research sites and to further eliminate methodological biases between sites, GEOHealth II project recruited trained dieticians to collect the dietary macronutrient intake data.

3.5.3 Biological Sample Collection

This study used de-identified whole blood samples from the parent project (GEOHealth II project). These blood samples were obtained in clean, enclosed portable stations set up near each study site by a qualified phlebotomist (Takyi et al., 2021). About 10ml of blood was collected and placed on a blood tube roller (Micro-Teknik) for 5 minutes in a trace metal-free BD Vacutainer tube with K₂EDTA. Next, the blood samples were transferred to the laboratory on dry ice and then stored in -80°C freezer frozen until analysis.

3.5.4 Blood glucose (HbA1c) analysis

Prior to the analysis, ~8µl of the de-identified whole blood samples were aliquoted into smaller vials and transported on ice to the Noguchi Memorial Institute (Nutrition Department) for HbA1c analysis. Next, HbA1c levels were analyzed in the de-identified whole blood samples using a High-Performance Liquid Chromatography (HPLC) (Agilent 1100 system (Santa Clara, CA, USA), composed of quaternary pump, auto sampler, diode array detector (DAD), and HP ChemStation Software was used).

3.6 Analytical Procedures

3.6.1 Macronutrient Analysis

Using Ghanaian food composition tables, the dietary macronutrient intake data was converted to grams (De Jager et al., 2018; Peprah, 2014). The ESHA F Pro® software was then used to do a comprehensive nutritional analysis to estimate individual macronutrient consumption. The amount of calories, proteins, carbohydrates, saturated fat, monounsaturated fat, polyunsaturated

fat, OMEGA 3, OMEGA 6, dietary fiber, cholesterol, and total fat consumed by each participant were obtained from the ESHA F Pro following nutritional analysis. Findings were then compared to an adult male's Dietary Reference Intake (DRI) (Mahan & Raymond, 2016).

3.6.2 Laboratory Metal Analysis and Quality Control

Metal Analysis

Baseline levels of Cd, and Pb in whole blood of e-waste recyclers and the control population have already been analyzed using the Inductively Coupled Plasma Mass Spectrometer (ICPMS; Varian 820MS) and published by Takyi et al (2021).

Quality Control Measures

Prior to use, all tubes and pipette tips were acid-washed (cleaned, immersed 24 hours in 10% hydrochloric acid, then rinsed three times in Milli-Q water). The specific reference materials were obtained from the Institute National de Sante Publique du Quebec. Although analytical standards were employed for each element to develop standard curves and gauge recovery, these reference materials did not cover all of the elements we investigated. To calculate analytical precision, each batch run includes duplicate processing (i.e., digestion and ICPMS analysis) of every 10th sample. Finally, procedural blanks were included in each batch run, and the theoretical detection limit was calculated as three times the standard deviation of the mean blank value for each element examined.



3.6.3 Laboratory Analysis of HbA1c and Quality Control Measures

Laboratory analysis of HbA1c levels

Diabetes is a chronic metabolic syndrome associated with increased blood glucose (or blood sugar) levels, which can cause serious damage to the body organs over time. The most common is type 2 diabetes, which affects adults and develops when the body becomes insulin resistant or produces insufficient insulin. Several diagnostic criteria have been approved by WHO as a validation tool for the diagnosis of diabetes such as fasting blood sugar, HbA1c, glucose intolerance and random blood sugar (Care & Suppl, 2020). Here in this study, the HbA1c was used as a diagnostic tool for diabetes in this project given their reliability (Florkowski, 2013; Sherwani et al., 2016).

4 μ l (microliters) of whole blood sample was aliquoted into 1ml of mobile phase A and inverted gently 8-9 times. The hemolyzate was transferred into HPLC vials and placed into the HPLC machine for analysis, of which conditions were put in place during the analysis; The column used was 35 x 4.6mm PolyCAT A® (3 μ m, 1500Å) with a back pressure of 1000PSI. Next the machine was set to a wavelength of 415nm, and a runtime of 5.2mins. 20 μ l of the hemolyzate was injected for the HbA1c analysis and compared accordingly.

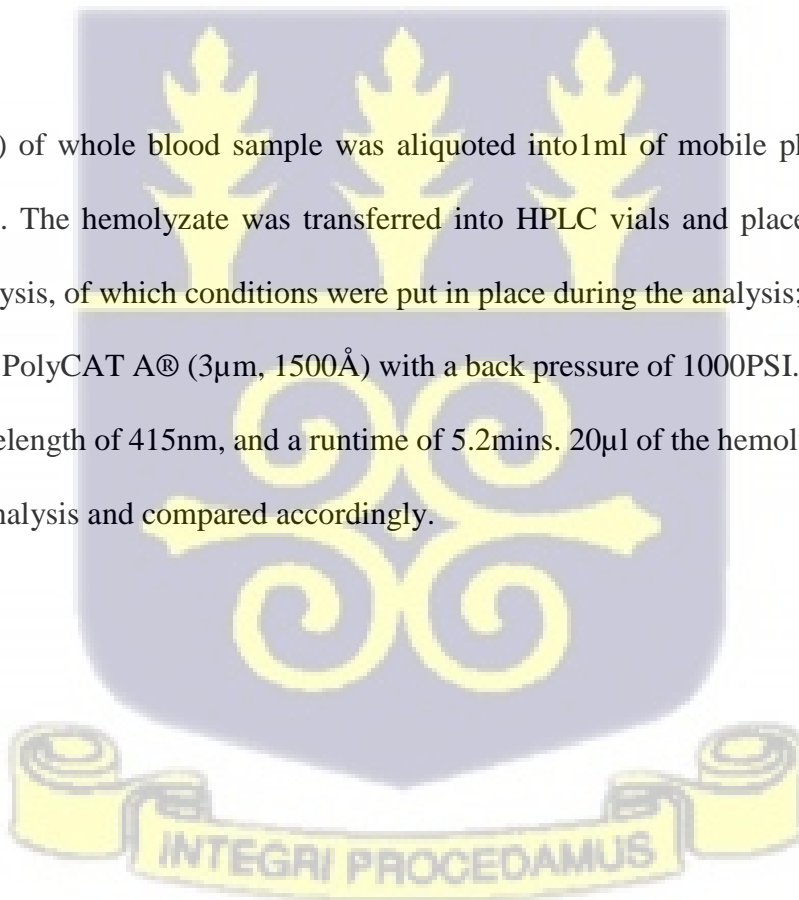




Figure 2: Image of HPLC machine



Figure 3: Analysis of HbA1c in de-identified whole blood samples

Quality controls used during HbA1c measurement

All micro tubes and HPLC vials were cleaned with distilled water then rinsed with mobile phase A. Reference materials, namely Control level I, Control level II and FASC were obtained from the PolyLC® group for calibration. Prior to sample analysis, Control I and II were reconstituted by pipetting 300µL of mobile phase A into each vial, stirred gently and then allowed to stand for 15mins. Next, 17µL of the reconstituted controls was pipetted into 1.983ml mobile phase A and then injected into the HPLC machine for calibration, prior to sample analysis. Procedural blanks were included in each batch run to check as part of the quality control measures employed. The mean recovery (precision) was 93%, which was well within quality-control protocol target limits (80-120). Samples were also compared to the standards to identify the retention peak times of interest. The reference ranges for HbA1c levels measured after calibration was between 4.5-6.9%.

3.7 Data Processing and Analysis

Levels of Cd, Pb, HbA1c as well as the amount of macronutrient consumed by the participants were statistically analyzed using descriptive statistics such as means, standard deviation, median and interquartile range. The prevalence of diabetes among e-waste recyclers and the comparison population was reported using descriptive statistics such as proportions and 95 percent confidence intervals (CIs). The relationship between metal exposures and HbA1c levels were assessed using a simple linear regression model. Similarly, the model was used to investigate the relationship between dietary macronutrient intake and blood glucose (HbA1c) levels of participants. Next, the joint relationship between metal exposures, dietary macronutrient intake and blood glucose levels were analyzed using the ordinary least square regression model.

3.8 Ethical approval and consent to participate

The University of Ghana and the University of Michigan Institutional Review Boards (IRB) approved the study protocols. The local chief of Agbogbloshie and Madina-Zongo permitted and allowed our research team to enter the community to conduct this study. Written informed consent was sought from each subject before participating in this study.



CHAPTER FOUR

4.0 RESULTS

4.1 Social-demographic Characteristics of Study Population

Briefly, the e-waste recyclers were significantly younger and less educated than the comparison population as published by Takyi et al., (2021). While a quarter of the e-waste recyclers had no formal education, more than half of the reference population had completed senior secondary or higher education (Takyi et al., 2021). Averagely more than fifty percent of the recyclers indicated they worked for about 9 hours each day and had been in the industry for about 10 years, with over half of the e-waste recyclers earning 20 to 100 Ghana cedis while 24% earning less than 20 Ghana cedis (Nti et al., 2020b; Takyi et al., 2021).

4.2 Metals Exposure

The mean blood Pb ($92.35 \pm 63.69 \mu\text{g/L}$) levels significantly exceeded the U.S. CDC reference level in about 84% of the e-waste recyclers, compared to the comparison group ($40.67 \pm 19.12 \mu\text{g/L}$) (Takyi et al 2021). Conversely, the average Cd levels in blood were significantly higher among the comparison group ($0.93 \pm 0.64 \mu\text{g/L}$), than the recycler group ($0.73 \pm 0.55 \mu\text{g/L}$) (Takyi et al 2021).

4.3 Dietary Macronutrients Intake

Dietary consumption of Omega 6 and Polyunsaturated fatty acids were significantly higher among the comparison group, than the recyclers [2.92 ± 3.86 , 4.55 ± 5.02 ; $p < 0.05$] (Table 1). Although not statistically significant, the comparison group consumed more calories, total fats, and saturated

fat [2067.34 ± 793.50 , 74.32 ± 50.63 , 6.58 ± 4.80 ; $p > 0.05$]. Similarly, no relationship was identified between dietary macronutrient intake and demographic factors including daily income accrued, age, religion, job-task performed as well as educational background. Below is a tabulated detail of the comparison of macronutrient intake between the e-waste recyclers and the comparison group (Table 1).

Table 1. Dietary macronutrient intake of e-waste recyclers and comparison group.

	E-waste Recycler		Comparison Group		p-value
	Mean \pm SD	Median (IQR)	Mean \pm SD	Median (IQR)	
Total Calories (g)	2050.05 \pm 673.05	1996.75 \pm 28.89	2067.34 \pm 793.50	1976.38 \pm 1165.5	0.75
Carbohydrates (g)	305.28 \pm 105.93	295 \pm 124.5	289.901 \pm 118.74	271 \pm 175	0.39
Proteins (g)	72.15 \pm 29.89	67.98 \pm 33.83	65.30 \pm 27.20	59.63 \pm 37.7	0.10
Total Fats (g)	66.57 \pm 32.46	61.48 \pm 32.93	74.32 \pm 50.63	62.9 \pm 37.85	0.64
Saturated Fats(g)	6.25 \pm 4.52	5.45 \pm 5.22	6.58 \pm 4.80	5.96 \pm 6.34	0.73
Mono Fats (g)	6.99 \pm 6.13	5.62 \pm 4.92	9.04 \pm 8.33	7.44 \pm 7.26	0.10
Poly fats (g)	3.40 \pm 5.00	1.94 \pm 2.37	4.55 \pm 5.02	2.95 \pm 3.77	0.02*
Omega 3(g)	0.16 \pm 0.14	0.12 \pm 0.18	0.19 \pm 0.17	0.14 \pm 0.19	0.46
Omega 6 (g)	1.89 \pm 2.50	1.21 \pm 1.66	2.92 \pm 3.86	1.88 \pm 1.95	0.02*
Cholesterol(mg)	123.12 \pm 97.21	91.5 \pm 132.15	99.75 \pm 77.56	91 \pm 91.4	0.28
Dietary Fibre (g)	19.32 \pm 11.11	17.58 \pm 13.5	20.89 \pm 13.97	17.43 \pm 14.98	0.96

P-Value notation: $p < 0.05^*$ for which reason their values were boldened

4.4 Prevalence of Diabetes

This study further investigated the prevalence of diabetes among the e-waste recyclers and comparison group (Table 2). Diabetes prevalence was significantly higher among the comparison population (Prev. = 41%, 95% CI: 28.41, 55.26%), compared to the recyclers (Prev. = 31.00%, 95% CI: 22.63, 40.84%) with a ($p < 0.05$) (Table 2). When blood glucose (HbA1c) levels were further categorized into participants with either regulated or unregulated blood glucose levels, 78% (95% CI: 64.83, 87.77) of the comparative population's blood glucose levels were unregulated (Table 2).

Table 2: Prevalence of diabetes among e-waste recyclers and comparison group

Blood Glucose Categories	E-waste recyclers % [95% CI]	Comparison Group % [95% CI]	χ^2 (p-value)
Blood Glucose Category 1			6.20 (0.05)
Low blood glucose levels (<4.5%)	27.00 [19.10, 36.69]	37.26 [24.81, 51.65]	
Normal Blood glucose levels (4.5-6.9%)	42.00 [32.63, 51.99]	21.57 [12.23, 35.17]	
High blood glucose levels (>6.9%)	31.00 [22.63, 40.84]	41.18 [28.41, 55.26]	
Blood Glucose Category 2			6.19 (0.01)
Regulated blood glucose (4.5-6.9%)	42.00 [32.63, 51.99]	21.57 [12.23, 35.17]	
Unregulated blood glucose levels (<4.5 and >6.9%)	58.00 [48.01, 67.37]	78.43 [64.83, 87.77]	

4.5 Relationship between metal exposures and blood glucose levels

No statistically significant relationship was found between blood Pb or Cd exposure and blood glucose levels of the e-waste recyclers and the comparison group, before and after adjusting for cigarette smoking, alcohol intake, daily income accrued, age, body mass index (BMI), recycler specific job task performed, marital status, and biomass exposure (Table 3). Similar results were obtained when analysis was limited to the recyclers or the comparison group.

Table 3: Relationship between metals exposures and blood glucose levels of e-waste recyclers and comparison group.

Metals ($\mu\text{g/L}$)	Blood Glucose Levels (HbA1c (%)) β [95% CI]
<i>E-waste recyclers and Comparison Group</i>	
B-Pb	0.003 [-.003, 0.009]
B-Cd	-0.193 [-0.854, 0.467]
<i>E-waste recyclers only</i>	
B-Pb	0.002 [0-.004, 0.008]
B-Cd	0.109 [-0.859, 1.077]
<i>Comparison group only</i>	
B-Pb	0.028 [-0.010, 0.066]
B-Cd	-0.589 [-1.740, 0.564]

p-value notation: $p < 0.05$ * Abbreviations: B-Pb: Blood Lead; B-Cd: Blood Cadmium; Random effects adjustments were made for cigarette smoking, alcohol intake, daily income accrued, age, BMI, recycler specific job task performed, marital status, & biomass exposure.

4.6 Association between dietary macronutrient intake and blood glucose levels

The consumption of macronutrients like OMEGA 3 and cholesterol from food was associated with significant increases in blood glucose levels of e-waste recyclers and the comparison group (Table 4a). Likewise, when the analyses was limited to the recyclers, intake of saturated fat, OMEGA 3 and cholesterol were associated with significant increases in blood glucose levels ($p < 0.05$) (Table 4b). On the contrary, no significant relationships were observed among the comparison population (Appendix 1).

Table 4a: Association between dietary macronutrient intake and blood glucose levels among e-waste recyclers and comparison group.

Dietary Macronutrients	Blood glucose levels (HbA1c (%)) β [95% CI]
Total Calories (g)	-0.0001 [-0.001, 0.0004]
Carbohydrates (g)	-0.0004 [-0.004, 0.003]
Proteins (g)	0.001 [-0.013, 0.014]
Total Fats (g)	-0.003 [-0.012, 0.006]
Saturated Fats(g)	0.061 [-0.025, 0.147]
Mono Fats (g)	0.005 [-0.048, 0.058]
Poly fats (g)	0.015 [-0.054, 0.085]
Omega 3(g)	3.397* [1.010, 5.784]
Omega 6 (g)	0.089 [-0.030, 0.209]
Cholesterol(mg)	0.005* [.001, 0.009]
Dietary Fibre (g)	-0.013 [-0.042, 0.018]

P-Value notation: $p < 0.05$ * for which reason their values were boldened



Table 4b: Relationship between dietary macronutrient intake and blood glucose levels of e-waste recyclers only

Dietary Macronutrients	Blood glucose levels (HbA1c (%)) β (95% CI)
Total Calories (g)	-0.0004 [-0.001, 0.0003]
Carbohydrates (g)	-0.002 [-0.007, 0.002]
Proteins (g)	-0.008 [-0.024, 0.008]
Total Fats (g)	-0.002 [-0.016, 0.010]
Saturated Fats(g)	0.097 *[0.0002, 0.193]
Mono Fats (g)	0.020 [-0.046, 0.087]
Poly fats (g)	0.019 [-0.061, 0.099]
Omega 3(g)	4.800 * [1.852, 7.748]
Omega 6 (g)	0.083 [-0.076, 0.243]
Cholesterol(mg)	0.004 * [0.0003, 0.009]
Dietary Fibre (g)	-0.003 [-0.042, 0.036]

P-Value notation: $p < 0.05$ * for which reason their values were boldened

4.7 Relationship between metal exposures, dietary macronutrient intake and blood glucose levels of e-waste recyclers and comparison group

In the joint model, exposure to Pb ($\beta=0.009$; 95% C: 0.001, 0.017; $p = 0.03$), coupled with dietary intake of cholesterol ($\beta=0.009$; 95% C: 0.001, 0.017; $p = 0.02$) were found to be associated with significant increases in blood glucose levels among the e-waste recyclers and comparison group (Table 5a). Similar results were found when analysis was limited to only recyclers (Appendix 2). Typically among the recyclers for instance, concurrently, while every 1 mg of cholesterol consumed from food was associated with a 0.7% increase in blood glucose levels (95% CI: 0.001, 0.012; $p = 0.015$; Appendix 2), $1\mu\text{g/L}$ of Pb was found to significantly augment blood glucose

levels by 0.9% (95% CI: 0.001, 0.017; $p = 0.025$; Appendix 2). Further in the model, high Pb exposure and saturated fat intake was associated with significant increases in blood glucose levels in both groups as well as among recyclers only (Table 5). In addition, dietary intake of OMEGA 3 was found to be associated with significant increases in blood glucose levels ($\beta = 6.797$; 95% CI: 2.960, 10.634; $p = 0.001$) in both groups after Cd exposure. Similar results were found when analysis was restricted to the recyclers (Appendix 3).



Table 5a: Relationship between Pb exposures, macronutrient intake and blood glucose levels of e-waste recyclers and comparison group.

Variables	Blood glucose levels (HbA1c (%)) β (95% CI)
B-Pb	0.007 [-0.002, 0.015]
Total Calories	-0.001 [-0.002, 0.001]
B-Pb	0.007 [-0.001, 0.015]
Carbohydrate (g)	-0.005 [-0.012, 0.001]
B-Pb	0.007 [-0.001, 0.015]
Protein (g)	0.0001 [-0.030, 0.030]
B-Pb	0.007 [-0.001, 0.015]
Total Fats (g)	-0.002 [-0.021, 0.016]
B-Pb	0.008* [0.00004, 0.016]
Saturated Fats (g)	0.136* [0.015, 0.258]
B-Pb	0.008 [-0.0005, 0.016]
Mono Fats (g)	0.044 [-0.037, 0.125]
B-Pb	0.008 [-0.001, 0.016]
Poly fats (g)	0.037 [-0.058, 0.132]
B-Pb	0.007* [0.0002, 0.015]
Omega 3 (g)	6.88* [3.247, 10.523]
B-Pb	0.008 [-0.0001, 0.016]
Omega 6 (g)	0.152 [-0.035, 0.339]
B-Pb	0.009* [0.001, 0.017]
Cholesterol (mg)	0.007* [0.001, 0.012]
B-Pb	0.007 [-0.001, 0.015]
Dietary Fibre (g)	-0.016 [-0.070, 0.037]

P-Value notation: $p < 0.05^*$ for which reason their values were boldened

Abbreviations: B-Pb: Blood Lead; Random effects adjustments were made for cigarette smoking, alcohol intake, daily income accrued, age, BMI, weight, educational status, years of work, marital status and mean probability of adequacy

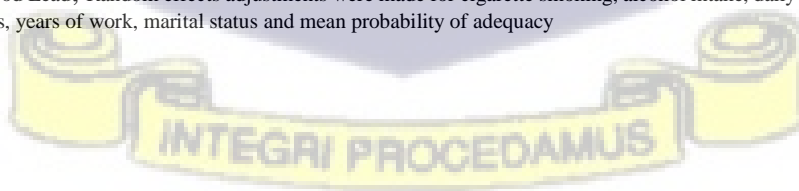
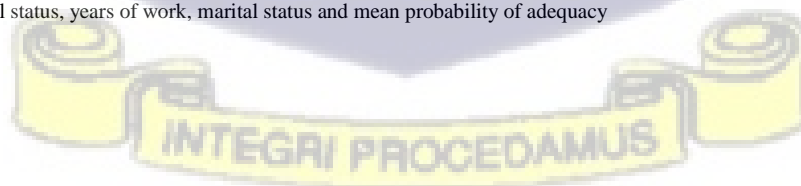


Table 6a: Relationship between Cd exposure, macronutrient intake and blood glucose levels of e-waste recyclers and comparison group.

Variables	Blood glucose levels (HbA1c (%)) β (95% CI)
B-Cd	0.250 [-0.879, 1.379]
Total Calories	-0.001 [-0.002, 0.0004]
B-Cd	0.223 [-0.900, 1.346]
Carbohydrate (g)	-0.005 [-0.012, 0.002]
B-Cd	0.242 [-0.903, 1.388]
Protein (g)	-0.001 [-0.032, 0.029]
B-Cd	0.273[-0.877, 1.423]
Total Fats (g)	-0.004 [-0.023, 0.015]
B-Cd	0.175 [-0.933, 1.284]
Saturated Fats(g)	1.121 [-0.005, 0.246]
B-Cd	0.254 [-0.885, 1.394]
Mono Fats (g)	0.029 [-0.053, 0.111]
B-Cd	0.251 [-0.892, 1.395]
Poly fats (g)	0.018 [-0.077, 0.113]
B-Cd	-0.088 [-1.133, 0.958]
Omega 3(g)	6.797* [2.960, 10.634]
B-Cd	0.232 [-0.895, 1.359]
Omega 6 (g)	0.121 [-0.069, 0.312]
B-Cd	0.265 [-.840, 1.370]
Cholesterol(mg)	0.005 [-0.0001, 0.011]
B-Cd	0.335 [-0.075, 1.483]
Dietary Fibre (g)	-0.020 [-0.075, 0.035]

P-Value notation: $p < 0.05^*$ for which reason their values were boldened

Abbreviations: B-Cd: Blood Cadmium; Random effects adjustments were made for cigarette smoking, alcohol intake, daily income accrued, age, BMI, weight, educational status, years of work, marital status and mean probability of adequacy



CHAPTER FIVE

5.0 DISCUSSION

Diabetes is progressively becoming one of the world's most common non-communicable diseases. Importantly, diabetes remains public health priority, considering its growing global burden and its implications on the quality of life as well as on the economy. Given that diabetes is now considered as rising global health issue, understanding the role of environmental and occupational exposures in the development or progression of diabetes remains critical.

5.1 Dietary macronutrient intake among e-waste recyclers and comparison population

Macronutrients are required in prescribed quantity to maintain a healthy body, by preventing illnesses, thus allowing the normal function of the body. The dietary macronutrient consumption data were obtained from the GEOHealth II Study.

To the best of my knowledge, this study is one of the first to investigate the caloric and macronutrient intake of groups exposed environmental toxins. Given that the e-waste recyclers performed rigorous tasks, it is expected that they would have high energy demand and will operate high metabolic rates as well. The current findings revealed that both e-waste recyclers and the comparison group did have the appropriate energy balance, given the average caloric amounts consumed. While literature on nutritional intake among groups exposed to toxicants remain limited, previous studies have also documented poor caloric/ energy intake among active males. For instance, like the recyclers, while average caloric intake was reported in the RODAMs study

(Galbete et al., 2017), both groups did not meet the DRI of 2500-3000 Kcal as set by the American Institute of Medicine (Trumbo et al., 2002).

Foods such as whole grain cereals, green leafy vegetables, lean meat, nuts are food sources rich in OMEGA 6 and polyunsaturated fats. The mean contributions of total fats (including saturated fats, polyunsaturated fats, omega 3, omega 6) carbohydrates and fiber for both e-waste recyclers and the comparison group were lower than acceptable DRI like findings reported by (Y. Zhao & Araki, 2021). The intake of insufficient quantities of polyunsaturated fats, omega-3 and omega-6 fatty acids could be attributable to increase cardiovascular risk, raised blood glucose levels, which may lead to an onset of diabetes and inflammation (Maki et al., 2018; Sokoła-Wysoczańska et al., 2018). However, adequate dietary intake of fiber could help regulate blood glucose and cholesterol levels in humans, inadequate intake may increase the risk of metabolic diseases including diabetes, hypertension and cancers (Lattimer & Haub, 2010). Furthermore, Dietary fiber helps to regulate blood glucose and cholesterol levels in humans (Lattimer & Haub, 2010). While the recyclers' protein intake exceeded the DRI, this may be acceptable given their exposure to cuts and muscle loss (Argilés et al., 2016), given the nature of their job.

5.2 Prevalence of diabetes among e-waste recyclers and comparison group

There are evidences of rising prevalence of diabetes in Ghana. Specifically, studies in the general population in Ghana have reported a diabetes prevalence between 3.3 and 6% among members of the general population, with the incidence increasing with age and being prevalent in urban than rural areas (Gatimu et al., 2016). Here in this study, diabetes prevalence among the e-waste

recyclers (31%) reported here was higher than prevalence reported for residents (22%) of abandoned metal mines in Korea (Son et al., 2015). The variations in documented prevalence could be attributable to occupational differences, metal exposures and sociodemographic variations.

Furthermore, diabetes was more prevalent in the comparison group, which might be linked to a lack of physical activity, resulting from a poorly planned urbanization that lacks a favorable environment for regular exercise, as well as uncontrolled food companies marketing junk food (Doherty et al., 2014). Some researchers have documented a higher prevalence of diabetes among sedentary workers compared to physically active groups, which is consistent with the current findings, where diabetes prevalence was higher in the comparator population than in the recyclers. For example, Gatimu et al., (2016) found that people with a low level of physical activity had a significantly higher prevalence of diabetes (6.74 %; 95% CI: 0.42–8.51) than those with a high level of physical activity (2.32%; 95% CI: 0.42–3.15) (Gatimu et al., 2016). Aside physical activity, the higher prevalence of diabetes documented among the comparison group could be linked to the increased environmental emissions like Cd from emissions of fumes from heavy vehicular traffic, biomass burnings and dust from unpaved roads (Nti et al., 2020b; Takyi et al., 2020; Takyi et al., 2021).

5.3 Relationship between metal exposures and blood glucose levels

Several studies have been conducted in an attempt to elucidate the link between heavy metal exposure and diabetes, yet inconsistent results have been reported (Barregard et al., 2013; Borné et al., 2014; Chang et al., 2021; Forte et al., 2013; Hansen et al., 2017). For instance, after adjusting

for age, body mass index, fasting blood glucose, total cholesterol, and triglyceride levels, HbA1c was positively related to the Log of blood Pb in a non-diabetic population (Chang et al., 2021). Further, Chang et al., (2021) also suggested Pb exposure as a risk factor of future development of diabetes. On the contrary, Cai et al., (2022), neither observed an overall effect of Pb and Cd plasma levels on HbA1c, nor the interaction effect of the metals on HbA1c (Cai et al., 2022). The variations in associations could be linked to level of exposure and concentration of metals exposed to.

Much like other baseline and even large-scale cohort studies (Barregard et al., 2013; Chang et al., 2021; Ji et al., 2021b), blood Cd was not associated with HbA1c levels. However, other authors have reported significant associations between Cd exposure and HbA1c levels in humans. For example, Borné et al., (2014). The absence of an association between Cd exposure and HbA1c levels can be explained by the lower blood mean levels of Cd reported among both e-waste recyclers and the comparison group in this study, as reported by Takyi et al., (2021).

5.4 Relationship between dietary macronutrient intake and HbA1c

Higher adherence to traditional dietary sources (meals based on starchy carbohydrates, lower fat and saturated fat content, more fruits and vegetables) has been linked to lower HbA1c levels (Churuangasuk et al., 2020). This study found positive relationships between total dietary fat and cholesterol intake, like findings reported elsewhere. For example, Churuangasuk et al., (2020) reported that higher cholesterol fat and saturated fat intakes were linked to higher percent HbA1c

among persons aged ≥ 16 years, during eight waves of the UK National Diet and Nutrition Survey (2008–2016) (Churuangasuk et al., 2020). Likewise, a significant increase in HbA1c, as well as LDL-cholesterol, triglycerides, and C-reactive protein ($p < 0.05$) was found to be related to increased fat intake (from 25% to 35%) (Vitale et al., 2016). Given that high saturated fat diet is linked to insulin resistance and the development of type 2 diabetes (von Frankenberg et al., 2017), appropriate dietary intake remains necessary to prevent the exacerbation of diabetes and related co-morbidities. Accordingly, consuming more of monounsaturated fat and polyunsaturated fat in place of saturated fat or carbohydrate has a tendency of improving HbA1c levels and may further have positive effects on insulin secretion (Imamura et al., 2016).

OMEGA 3 fatty acids have been shown to have significant impacts on human health in clinical, experimental, and epidemiological studies (Reimers & Ljung, 2019; Shahidi & Ambigaipalan, 2018). The low dietary intake of omega-3 fatty acids in e-waste recyclers and the comparison group, on the other hand, might explain the positive relationship between omega-3 fatty acids and HbA1c levels measured in this study. Some studies have shown that omega-3 has potential anti-inflammatory properties and a positive effect on improving insulin sensitivity (González-Pérez et al., 2009; Yan et al., 2013). Therefore, people living in both polluted and cleaner cities ought to be educated on the need for adequate intake of healthy fats like Omega-3 and early supplementation to boost their metabolic health. In addition, some authors have detailed that fish-derived OMEGA 3 fatty acids appear to be particularly protective against pollutant-induced inflammation, and other forms of lipid disposition may serve as a regulatory platform for OMEGA 3 fatty acid-mediated cellular protection (Layne et al., 2010; Majkova et al., 2010). Despite the evidence that both the quantity and type of carbohydrate in a food affect blood glucose levels, and total amount of

carbohydrate consumed is the primary predictor of glycemic response (Hakeem et al., 2018; Wolever et al., 2008), this study found no link between carbohydrate intake and HbA1c. Further, the current study neither found significant associations between carbohydrate intake nor proteins with HbA1c levels.

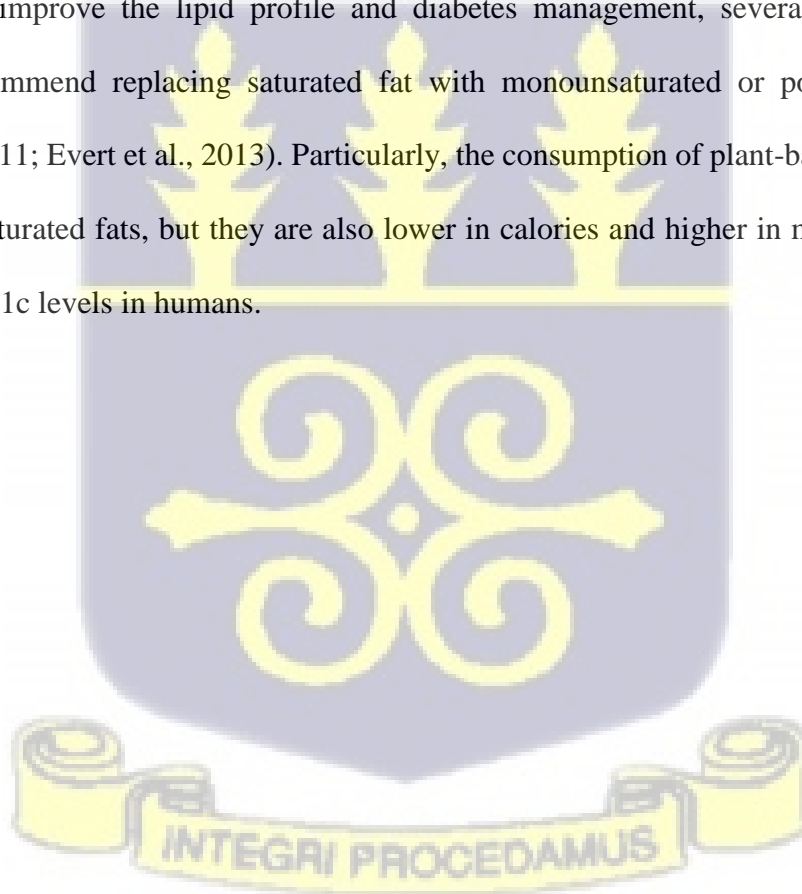
5.5 Relationship between metal exposures dietary macronutrient intake and blood glucose levels.

The findings of this study seem to suggest that a poor dietary macronutrient intake combined with metal exposures may increase HbA1c levels in humans. In the joint effect model, for example, high Pb exposure combined with dietary cholesterol and saturated fat consumption was found to be associated with a significant increase in HbA1c levels in both groups as well as recyclers only. This could be attributed to poor dietary habits coupled with increased metal exposure associated with informal e-waste recycling.

While Pb lead is known to trigger oxidative stress by activating reactive oxygen species (ROS) and inhibiting the insulin-signaling pathway, several studies have found that it increased insulin resistance and diabetes (Matović et al., 2015; Tangvarasittichai, 2015; Zhai et al., 2015). In humans, macronutrients such as dietary cholesterol and saturated fat intake have also been shown to increase insulin resistance (Biobaku et al., 2019; Dandona et al., 2010; Wali et al., 2021). Although temporality cannot be assumed due to the cross-sectional study design employed, the combined effects of Pb and macronutrients like cholesterol and saturated fats may be linked to

increases in participants' HbA1c levels. Despite the fact that this study measured lower intake of unhealthy fats such as dietary cholesterol and saturated fats, blood glucose levels were found to be significantly associated with increased Pb exposure. These findings highlight the importance of consistent and appropriate dietary education in both toxicant-exposed groups and the general population to prevent unbalanced dietary fat intake and increased diabetes risks.

Evidences from this study may serve as basis to help inform dietary guidelines for macronutrients that can improve metabolic health in both exposed groups like recyclers as well as in the general population. To improve the lipid profile and diabetes management, several nutrition-related institutions recommend replacing saturated fat with monounsaturated or polyunsaturated fat (Dyson et al., 2011; Evert et al., 2013). Particularly, the consumption of plant-based meals are not only lower in saturated fats, but they are also lower in calories and higher in minerals and fiber, requisite to HbA1c levels in humans.



CHAPTER SIX

CONCLUSION

In conclusion, aside the adequate intake of proteins, this study highlights inadequate intake of macronutrients like carbohydrates, fiber and polyunsaturated fats (OMEGA 3 and OMEGA 6) among e-waste recyclers and the comparison group. Prevalence of diabetes was higher among the comparison group, given their sedentary job nature, relative to recyclers who performed vigorous work-tasks. Although unhealthy fats like dietary cholesterol and saturated fats were inadequately consumed, the exposure to Pb and Cd, together with a reduced intake of these fats may still increase the risk of diabetes among both e-waste recyclers and the general population.

RECOMMENDATIONS:

- Research and Education
 - It is suggested that mechanistic studies be designed to focus on how macronutrients and pollutants interfere with glucose metabolism.
- Government
 - Public health education and promotion focusing on adequate nutrient intake and healthy eating strategies in both e-waste recyclers and the general populations explored and intensified in the Ghana.

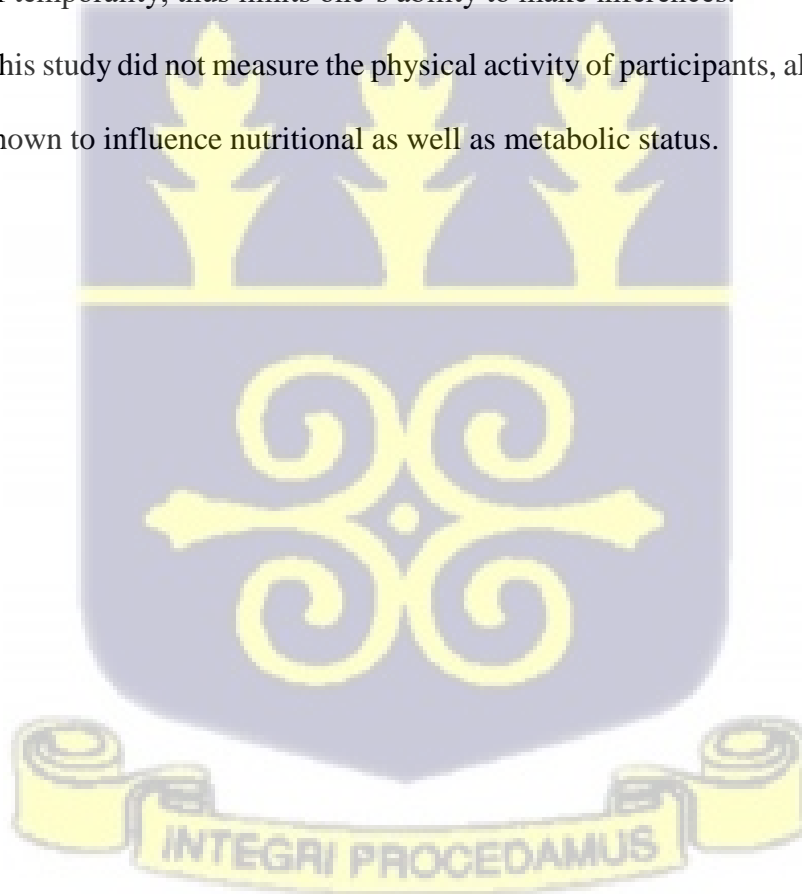


Strengths of the study:

- To the best of my knowledge, this study is the first to investigate the joint relationship between metal exposures, dietary macronutrient intake and blood glucose levels among male e-waste recyclers in Ghana and elsewhere.
- Secondly, this study provides firsthand data on the prevalence of diabetes among toxicant-exposed groups in Ghana, such as e-waste recyclers.

Limitations of the study:

- Employing a cross sectional design for this study does not allow for the assumption of temporality, thus limits one's ability to make inferences.
- This study did not measure the physical activity of participants, although it has been shown to influence nutritional as well as metabolic status.



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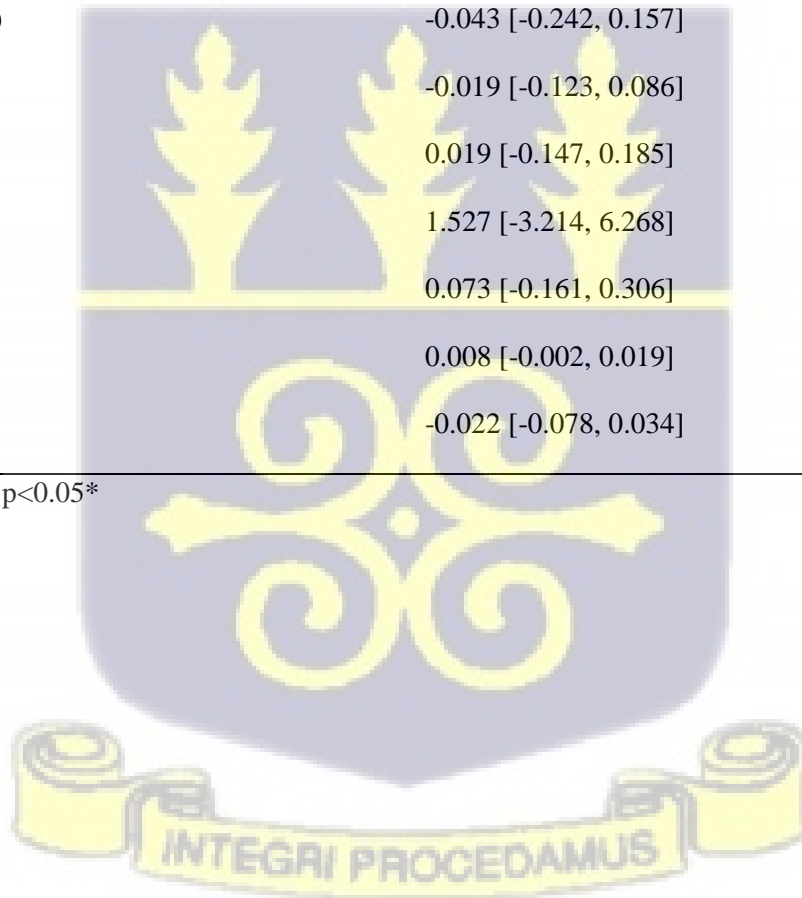
APPENDICES

APPENDIX I

Table 4c. Relationship between macronutrient intake and blood glucose levels of comparison group.

Dietary Macronutrients	Blood glucose levels (HbA1c (%)) β (95% CI)
Total Calories (g)	0.000 [-.001, 0.001]
Carbohydrates (g)	0.003 [-0.004, 0.010]
Proteins (g)	0.019 [-0.009, 0.047]
Total Fats (g)	-0.001 [-0.016, 0.015]
Saturated Fats(g)	-0.043 [-0.242, 0.157]
Mono Fats (g)	-0.019 [-0.123, 0.086]
Poly fats (g)	0.019 [-0.147, 0.185]
Omega 3(g)	1.527 [-3.214, 6.268]
Omega 6 (g)	0.073 [-0.161, 0.306]
Cholesterol(mg)	0.008 [-0.002, 0.019]
Dietary Fibre (g)	-0.022 [-0.078, 0.034]

P-Value notation: $p < 0.05^*$



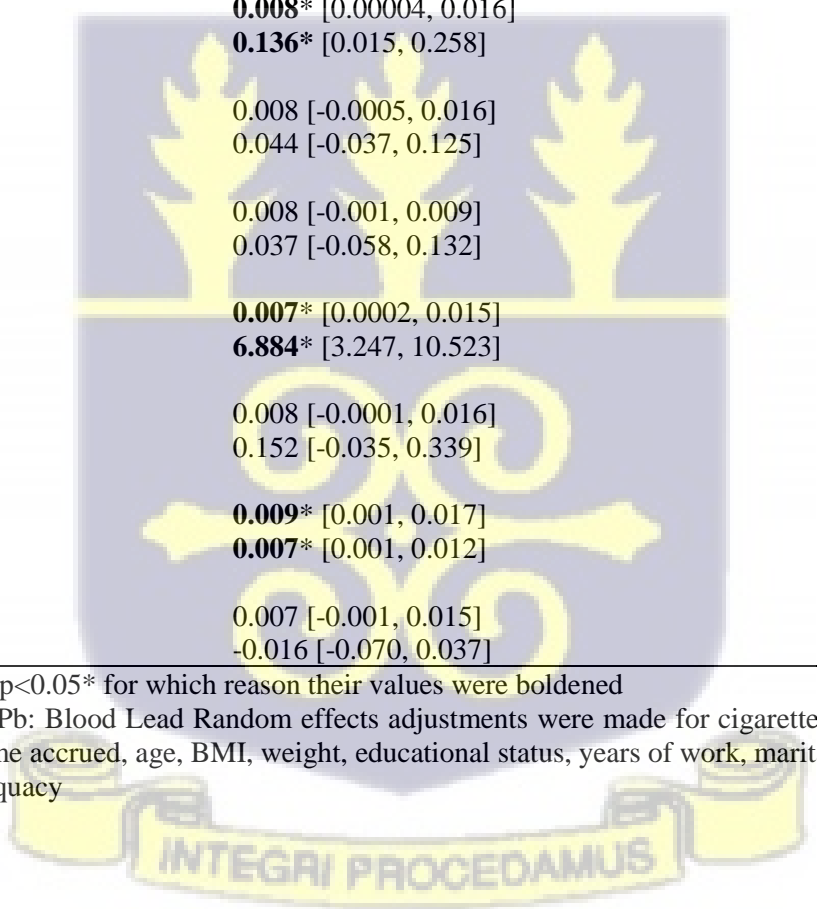
APPENDIX II

Table 5b: Relationship between Pb exposure, macronutrient intake and blood glucose levels of e-waste recyclers.

Variables	Blood glucose levels (HbA1c (%)) β (95% CI)
B-Pb	0.007 [-0.002, 0.015]
Total Calories	- 0.001 [-0.002, 0.001]
B-Pb	0.007 [-0.001, 0.015]
Carbohydrate (g)	-0.005 [-0.012, 0.001]
B-Pb	0.007 [-0.001, 0.015]
Protein (g)	-0.0001 [-0.030, 0.030]
B-Pb	0.007 [-0.001, 0.015]
Total Fats (g)	-0.002 [-0.021, 0.016]
B-Pb	0.008* [0.00004, 0.016]
Saturated Fats(g)	0.136* [0.015, 0.258]
B-Pb	0.008 [-0.0005, 0.016]
Mono Fats (g)	0.044 [-0.037, 0.125]
B-Pb	0.008 [-0.001, 0.009]
Poly fats (g)	0.037 [-0.058, 0.132]
B-Pb	0.007* [0.0002, 0.015]
Omega 3(g)	6.884* [3.247, 10.523]
B-Pb	0.008 [-0.0001, 0.016]
Omega 6 (g)	0.152 [-0.035, 0.339]
B-Pb	0.009* [0.001, 0.017]
Cholesterol(mg)	0.007* [0.001, 0.012]
B-Pb	0.007 [-0.001, 0.015]
Dietary Fibre (g)	-0.016 [-0.070, 0.037]

P-Value notation: p<0.05* for which reason their values were boldened

Abbreviations: B-Pb: Blood Lead Random effects adjustments were made for cigarette smoking, alcohol intake, daily income accrued, age, BMI, weight, educational status, years of work, marital status and mean probability of adequacy



APPENDIX III

Table 5c: Relationship between metal exposures (Pb) macronutrient intake and blood glucose levels of comparison group

Variables	Blood glucose levels (HbA1c (%)) β (95% CI)
B-Pb	0.026 [-0.013, 0.065]
Total Calories	0.0002 [-0.001, 0.001]
B-Pb	0.025 [-0.014, 0.065]
Carbohydrate (g)	0.001[-0.006, 0.008]
B-Pb	0.002 [-0.004, 0.008]
Protein (g)	- 0.024 [-0.014, 0.062]
B-Pb	0.028 [-0.011, 0.066]
Total Fats (g)	-0.001 [-0.016, 0.015]
B-Pb	[0.027 [-0.011, 0.066]
Saturated Fats(g)	-0.032 [-0.229, 0.165]
B-Pb	0.027 [-0.011, 0.065]
Mono Fats (g)	-0.011 [-0.114, 0.093]
B-Pb	0.028 [-0.010, 0.067]
Poly fats (g)	0.024 [-0.140, 0.187]
B-Pb	0.030 [-0.010, 0.070]
Omega 3(g)	1.329 [-3.47, 6.134]
B-Pb	0.029 [-0.011, 0.068]
Omega 6 (g)	0.0536 [-0.179, 0.286]
B-Pb	0.033 [-0.004, 0.070]
Cholesterol(mg)	0.010[-0.001, 0.020]
B-Pb	0.029 [-0.010, 0.067]
Dietary Fibre (g)	-0.019 [-0.075, 0.037]

P-Value notation: $p < 0.05^*$

Abbreviations: B-Pb: Blood Lead; B-Cd: Blood Cadmium; Random effects adjustments were made for cigarette smoking, alcohol intake, daily income accrued, age, BMI, recycler specific job task performed, marital status

APPENDIX IV

Table 6b: Relationship between metal exposures (Cd), macronutrient intake and blood glucose levels of e-waste recyclers

Variables	Blood glucose levels (HbA1c (%)) β (95% CI)
B-Cd	0.250 [-0.879, 1.379]
Total Calories	-0.001 [-0.002, 0.0004]
B-Cd	0.223 [-0.900, 1.346]
Carbohydrate (g)	-0.005 [-0.012, 0.002]
B-Cd	0.242 [-0.903, 1.388]
Protein (g)	-0.001 [-0.032, 0.029]
B-Cd	0.273[-0.877, 1.423]
Total Fats (g)	-0.004 [-0.023, 0.015]
B-Cd	0.175 [-0.933, 1.284]
Saturated Fats(g)	1.121 [-0.005, 0.246]
B-Cd	0.254 [-0.885, 1.394]
Mono Fats (g)	0.029 [-0.053, 0.111]
B-Cd	0.251 [-0.892, 1.395]
Poly fats (g)	0.018 [-0.077, 0.113]
B-Cd	-0.088 [-1.133, 0.958]
Omega 3(g)	6.797* [2.960, 10.634]
B-Cd	0.232 [-0.895, 1.359]
Omega 6 (g)	0.121 [-0.069, 0.312]
B-Cd	0.265 [-0.840, 1.370]
Cholesterol(mg)	0.005 [-0.0001, 0.011]
B-Cd	0.335 [-0.814, 1.483]
Dietary Fibre (g)	-0.020 [-0.075, 0.035]

P-Value notation: p<0.05* for which reason their values were boldened

Abbreviations: B-Cd: Blood Cadmium; Random effects adjustments were made for cigarette smoking, alcohol intake, daily income accrued, age, BMI, weight, educational status, years of work, marital status and mean probability of adequacy

APPENDIX V

Table 6c: Relationship between metal exposures (Cd) macronutrient intake and blood glucose levels of comparison group.

Variables	Blood glucose levels (HbA1c (%)) β (95% CI)
B-Cd	-0.541 [-1.720, 0.638]
Total Calories	0.0003 [-0.001, 0.001]
B-Cd	-0.558 [-1.726, 0.609]
Carbohydrate (g)	0.002 [-0.005, 0.009]
B-Cd	-0.456 [-1.623, 0.711]
Protein (g)	0.017[-0.012, 0.046]
B-Cd	-0.599 [-1.778, 0.580]
Total Fats (g)	-0.001 [-0.017, 0.014]
B-Cd	-0.580 [-1.750, 0.589]
Saturated Fats(g)	-0.039 [-0.239, 0.160]
B-Cd	-0.585 [-1.755, 0.586]
Mono Fats (g)	-0.018 [-0.122, 0.086]
B-Cd	-0.624 [-1.812, 0.564]
Poly fats (g)	0.028 [-0.140, 0.197]
B-Cd	-0.525 [-1.728, 0.679]
Omega 3(g)	0.674 [-4.221, 5.568]
B-Cd	-0.543 [-1.740, 0.654]
Omega 6 (g)	0.048 [-0.189, .286]
B-Cd	-0.490 [-1.632, 0.653]
Cholesterol(mg)	0.008 [-0.003, 0.018]
B-Cd	-0.621 [-1.789, 0.548]
Dietary Fibre (g)	-0.019 [-0.076, 0.039]

P-Value notation: p<0.05* Abbreviations: B-Pb: Blood Lead; B-Cd: Blood Cadmium; Random effects adjustments were made for cigarette smoking, alcohol intake, daily income accrued, age, BMI, recycler specific job task performed, marital status

