

**ASSOCIATION OF CARCINOGENIC HEAVY METALS IN FOODS, WITH COLORECTAL CANCER,
IN NYAMBENE, MERU COUNTY, KENYA,**

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**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE DEGREE OF MASTER OF PUBLIC
HEALTH OF KENYA METHODIST UNIVERSITY.**

OCTOBER 2025

DECLARATION AND RECOMMENDATION

This thesis is my original work and has not been presented for a degree or any other award in any other university

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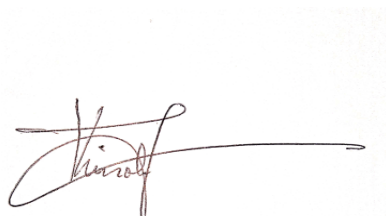
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DEDICATION

This research is dedicated to my family

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ABSTRACT

Colorectal cancer is a growing public health concern in Kenya, especially in the Kiegoi sub-location of Nyambene region where incidence rates are rising without clear etiology. This study aimed to quantify arsenic, cadmium, chromium, mercury and lead in staple foods from Kiegoi and explore their association with colorectal cancer incidence in the area. Cross sectional retrospective review of Meru Teaching and Referral Hospital oncology department records from 2018-2024 was conducted which limits the causal inference of heavy metals in colorectal cancer. Samples of beans, arrowroots, potatoes and maize were collected using simple randomized stratified sampling from each of the five agro-ecological zones in Kiegoi. The samples were then digested with nitric acid, perchloric acid and hydrochloric acid and analyzed by inductively coupled plasma mass spectroscopy (ICP-MS). The overall crude incidence of colorectal cancer in Kiegoi was 1211 per 100,000 of the population. The age specific standardized rate (WHO standard population) was 599 per 100,000 of the population. Cadmium levels were significantly below regulatory thresholds (below FAO/WHO limits) in all foods. Mercury and chromium levels exceeded limits in 100 % of the samples; arsenic and lead exceeded levels in 50 %. Multivariate logistics regression identified lead (OR=17.7), mercury (OR=3.5) and arsenic (OR=2.5) as significant predictors for colorectal cancer. Cadmium showed a negative association while chromium's effect was marginal. Widespread contamination by mercury chromium and lead in staple foods most likely contributes to Nyambene's colorectal cancer burden. Policy measures should include routine environmental surveillance, soil remediation and targeted public health screening.

Keywords: Colorectal cancer, prevalence, TNM staging, significant, heavy metals, ICP MS.

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ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectroscopy
AFS	Atomic Fluorescence Spectroscopy
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemist
ATP	Adenosine triphosphate
CRC	Colorectal cancer
CT	Computerized Tomography
DIM	Daily intake of metal
DMA	Dimethylarsonic
DNA	Deoxy Ribo-nucleic Acid
FAO	Food and Agriculture Organization
FDA	Food and Drug Authority
IARC	International Agency for Research on Cancer
ICD	International Classification of Diseases
ILCR	Incremental lifetime cancer risk
ICP-MS	Inductively Coupled mass spectroscopy
ICP-OES	Inductively Coupled Optical Emission Spectroscopy
KEBS	Kenya Bureau of Standards
KEPHIS	Kenya Plant Health Inspectorate
MOH	Ministry of Health
MRI	Magnetic Resonance Imaging
NAA	Neutrino Activation Analysis
NACOSTI	National Commission for Science Technology and Innovation

NEMA	National Environment Management Authority
NCI	National Cancer Institute
NCI-K	National Cancer Institute Kenya
OSHA	Occupational Safety and Health Authority
PPB	Parts per billion
PPM	Parts per million
ROS	Reactive Oxygen Species
SPSS	Statistical Package for Social Sciences
THQ	Target Hazard Quotient
TNM	Tumor Node and Metastasis
USEPA/ EPA	United States Environmental Protection Agency
WHO	World Health Organization
XRF	X Ray Florescence

CHAPTER ONE

INTRODUCTION

1.1 Background information

Cancer remains a major global public health concern and one of the leading causes of mortality worldwide. According to the World Health Organization, in 2020, there were around 19.3 million new cases and 10 million fatalities reported (World Health Organization [WHO], 2025). The worldwide impact of cancer is expected to increase in the coming decades due to factors such as an aging population, changing lifestyles, environmental pollution, and increased exposure to carcinogens (Bray et al., 2021). Common types of cancer globally consist of lung, breast, colorectal, prostate, and stomach cancers, with variations depending on geographical, genetic, and environmental influences (Ferlay et al., 2020).

In Africa, cancer incidences are rising rapidly due to urbanization, industrialization, pollution, lifestyle changes, and limited access to early detection and treatment (Fidler et al., 2021). Many African countries, including Kenya, are undergoing an epidemiological transition, where communicable diseases are declining while non-communicable diseases such as cancer are increasing. Several factors contribute to this trend, including environmental pollution from industrial and agricultural activities, dietary shifts towards processed foods containing preservatives, and limited

healthcare infrastructure for screening and treatment (Ngoma, 2019). Occupational exposure to carcinogens further exacerbates the risk, while some chronic infections increase susceptibility to cervical and liver cancer (Dagnachew et al., 2022).

In Kenya, cancer accounts for approximately 7% of annual deaths, with around 42,000 new cases and 29,000 deaths recorded in 2022 (National Cancer Institute of Kenya [NCI-K], 2023). Prevalent types of cancer are breast, cervical, esophageal, prostate, and colorectal cancer. The elevated death rate is primarily attributed to diagnoses being made at advanced stages and limited access to quality treatment, which significantly reduces survival rates (Makau et al., 2021). Over 60% of those affected are below the age of 70. In Kenya, the likelihood of developing cancer before turning 75 is 14%, while the projected likelihood of death due to the illness is around 12%. In many developing countries, the rapid increase in cancer cases can be attributed to greater exposure to risk factors, including tobacco use, high alcohol consumption, and contact with environmental carcinogens. Additionally, exposure to carcinogens, including agrochemicals, industrial pollutants, and heavy metal contamination, is an emerging issue (Korir et al., 2020).

Certain risk factors, including excessive tobacco use, high alcohol intake, and a Western-style diet, are linked to the onset of colorectal cancer (CRC). It ranks as the third most commonly diagnosed cancer and is the second

leading cause of cancer-related fatalities globally. While early detection can greatly enhance survivorship, CRC presents with no specific signs at the onset, decreasing the chances of it being identified. A number of treatment modalities are available ranging from approaches such as surgery, chemotherapy, molecular therapy, targeted therapy and radiation.

Health records of Nyambene region of Meru County, particularly Kiegoi, indicate a rising trend in colorectal cancer cases, raising concerns about potential environmental risk factors (Njoroge et al., 2021). Heavy metal contamination in food is a major concern, probably due to the widespread use of agricultural chemicals, fertilizers, and pesticides (Kimani et al., 2020). Although aspects such as genetics, lifestyle, and diet have been thoroughly examined, the impact of heavy metals like arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg) and lead (Pb) has not been adequately investigated in Nyambene. These heavy metals do not decompose and tend to persist in the environment, with the potential to accumulate in food crops, posing serious health risks to consumers.

Heavy metals are elements with substantial densities and atomic weights that typically exceed 5g/cm³. They are required for normal body metabolism in small quantities but majority are toxic even at certain concentrations. Lead, arsenic, chromium, cadmium and mercury have all been identified as metals of public health significance by the WHO due to their associated toxicities.

1.2 Statement of the Problem

Colorectal cancer (CRC) incidence in Kiegoi, Nyambene, has risen sharply yet local risk factor data remains scarce. Exposure to carcinogenic heavy metals (Arsenic, cadmium, chromium, lead and mercury) via dietary intake is hypothesized to drive this trend by promoting oxidative stress, inflammation, DNA damage, and oncogenic signaling. However no studies have quantified heavy metals in Kiegoi's staple food or correlated dietary exposure with CRC incidences hindering targeted prevention strategies.

1.3 Purpose of study

This research explored the possible connection between exposure to carcinogenic heavy metals through dietary sources and the onset of colorectal cancer in the Kiegoi area of Nyambene region. This study specifically measured the concentrations of arsenic, cadmium, mercury, chromium, and lead in foods in Kiegoi, and investigated the potential relationship between dietary exposure and the incidence of colorectal cancer. The results are scientific data to guide public health initiatives and efforts to prevent cancer in the region.

1.4 Objectives

1.4.1 General objective

To determine the association between dietary exposure to arsenic, cadmium, chromium, mercury and lead in staple foods and the prevalence of colorectal

cancer in Kiegoi, Nyambene.

1.4.2 Specific objectives

1. To determine the crude prevalence and age standardized rate of colorectal cancer in Kiegoi from 2018-2024.
2. To determine As, Cd, Cr, Hg and Pb concentration in maize, beans, potatoes and arrowroots from Kiegoi and benchmark the measured concentrations with FAO/WHO food safety limits.
3. To compare the levels of heavy metals contamination among the four foods.
4. To determine the association between colorectal cancer prevalence and heavy metal contamination of foods and in Kiegoi.

1.5 Hypothesis and research questions

H1: There is a significant correlation between heavy metal contamination of foods and colorectal cancer prevalence in Kiegoi Nyambene, Meru County.

H0: There is no significant correlation between heavy metal contamination of foods and colorectal cancer prevalence in Kiegoi Nyambene, Meru County.

Research questions

- I. What is the prevalence of cancer in Kiegoi?
- II. What are the levels of As, Cd, Cr, Hg and Pb in staple foods in Kiegoi?

- III. Do the levels of these heavy metals significantly vary across different foods?
- IV. What is the association of carcinogenic heavy metals and colorectal cancer prevalence in Kiegoi?

1.6 Justification of the study

Colorectal cancer (CRC) is emerging as a significant public health issue in Kiegoi, with increasing incidences being recorded. In Kiegoi, access to specialized cancer care is limited with the nearest cancer treatment center being Meru Teaching and Referral Hospital. This has led to late diagnosis of colorectal cancer with most cases being detected at advanced stages, causing poor prognosis and catastrophic health expenditures.

The Ministry of Health Kenya, through the Kenya National Cancer Control Strategy (NCCS) 2023–2027 identifies prevention and early detection as among the strategic pillars for reducing the national cancer burden. Prevention interventions must be informed by robust scientific evidence on modifiable risk factors such as exposure to carcinogens such as heavy metals through diet. This dietary exposure is a theorized but under-researched determinant of CRC development in Kiegoi.

This study is targeted at filling this critical knowledge gap by quantifying the levels of carcinogenic heavy metals in staple food crops in Kiegoi. Findings of this study will provide informative data that can be harnessed to inform targeted public health response and policy decisions for colorectal cancer

prevention in this area.

1.7. Limitations of the study

- i. Causal Inference: Given the cross-sectional design of the study, it will be difficult to establish a direct cause-and-effect relationship between exposure to heavy metals and colorectal cancer. The research will mainly focus on identifying correlations rather than confirming causality.
- ii. Temporal Limitations: The study depends on a single sampling of foods, which may not accurately represent fluctuations in heavy metal levels that occur seasonally or from year to year.
- iii. Laboratory Constraints: Financial resources may limit the number and precision of tests performed on crop samples.
- iv. Generalizability of Findings: The findings from Nyambene may not be relevant to other agricultural areas in Kenya that have different environmental conditions or farming methods.
- v. Health Data Quality: The availability and thoroughness of hospital records may differ, which could affect the accuracy and completeness of the colorectal cancer data used in this study.

1.8 Delimitation of the study

- i. Geographical Focus: The study is limited to the Kiegoi area of Nyambene region in Meru County, chosen for its high reported occurrences of colorectal cancer.

- ii. Selected Heavy Metals: This research is confined to five known carcinogenic heavy metals due to the recognized health associated with them.
- iii. Target foods: The study only includes four foods: arrowroots, maize, beans and potatoes chosen since they are the most consumed foods in the region.
- iv. Health Focus: The health impact examined here is specifically colorectal cancer, even though heavy metals may also relate to other types of cancer or health issues not addressed in this study.
- v. Study Design Constraints: The research utilizes a cross-sectional method, which is appropriate for initial data gathering but does not facilitate tracking long-term exposure or analyzing temporal trends.

1.9 Significance of study

The research aims to provide data regarding the presence of carcinogenic heavy metals in foods from Kiegoi, as well as their potential role in the development of colorectal cancer. The findings of this research can guide both local and national authorities in creating or enhancing policies related to food safety and environmental conservation.

1.10 Assumptions of the study

- i. Cases of colorectal cancer in Nyambene may be affected by

environmental and dietary factors.

- ii. Laboratory analysis of food samples can effectively identify and measure the levels of heavy metals present.
- iii. Cancer registries from the region can offer reliable statistics regarding the prevalence and incidence of colorectal cancer.

1.11 Operational Definition of Terms

- i. Carcinogenic Heavy Metals: Toxic metallic substances that are acknowledged by global health Organizations (e.g., WHO, IARC) as having the capability to induce cancer in humans.
- ii. Exposure: The consumption of food crops that have been contaminated with heavy metals over time, evaluated through dietary surveys and heavy metal testing of crop samples.
- iii. Significant Relationship: A statistical correlation generally identified using a p-value less than 0.05 as determined through statistical analysis such as Pearson correlation or logistics regression.
- iv. Sensitivity: Ability of the analytical instrument to differentiate between small differences in analyte concentrations.
- v. Blank: Sample of analyte free medium prepared using the digestion reagents

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Sections discussed include: Cancer, colorectal cancer prevalence, diagnosis and risk factors, heavy metals and colorectal cancer, health implications of heavy metals, conceptual framework and the research gaps.

2.2 Cancer

Cancer encompasses a variety of diseases in which body cells grow and reproduce in an uncontrolled manner and may end up spreading to other parts of the body. Tumor suppressor genes, DNA repair genes and proto-oncogenes help to prevent this uncontrolled cell growth. Proto-oncogenes are genes responsible for normal body cells growth and division. They however have the potential to become oncogenes (genes responsible for cancer), when triggered by certain events such as mutations in nucleic acid, chromosomal rearrangement and gene amplification. Most oncogenes result in non-functional cells that are unable to reproduce and therefore the cell is not harmed. Few oncogenes may result in a cell that is able to reproduce causing passing down of the mutation to the daughter cell resulting in harming of the cell (National Cancer Institute [NCI], 2021).

Tumor suppressor genes serve to regulate the cell growth cycle, thereby inhibiting the uncontrolled proliferation of cells. Their role is crucial in

impeding the cell cycle and the development of tumor cells. Unlike oncogenes, which must be activated for cancer to develop, tumor suppressor genes must be inactivated for cancer to develop. Inactivation can be due to mutations or loss of the alleles responsible for the gene (Joyce et al., 2023).

DNA repair genes are involved in the identification of damages in the DNA and the repair of these damages. They do these by mechanisms such as recognition of DNA lesions and preventing wrong incorporations of nucleic acids. DNA repair genes are crucial when it comes to preventing cancer (Torgovnick and Schumacher, 2015).

Globally the most prevalent cancers are breast, lung, colon and rectum (colorectal) and prostate cancer (WHO, 2023).

2.2.1 Breast cancer

Breast cancer most commonly begins in the cells lining the milk ducts (ductal carcinoma), though it can also arise in the milk-producing lobules, a condition known as lobular carcinoma. It remains the most prevalent cancer among women worldwide, accounting for more than 10% of all newly diagnosed cancers annually. Furthermore, it is the second highest cause of cancer-related mortality in women globally (National Institutes of Health [NIH], 2024). The number of breast cancer incidences per year has been steadily rising and are currently over 2.26 million cases, with more than 685, 000 deaths annually (WHO, 2020).

It is as a result of alterations in the physiology of breast cells. It generally originates in the cells lining the ducts that transport milk from the glands to the nipple; this specific subtype is referred to as ductal carcinoma. Cancer can also originate from the lobules, which are the groups of glands that produce milk; this type is known as lobular carcinoma. The two types of breast cancers are divided into insitu meaning it has not metastasized or invasive when it has metastasized (Obeagu & Obeagu, 2024)

The condition can present with a number of symptoms. The initial symptom that is often observed is typically a lump or a region of dense breast tissue, which may be either painful or painless. Other symptoms include an alteration in the size or shape of one or both breasts, fluid coming from either nipple (which may be tinged with blood), a mass or swelling in either armpit, indentations on the surface of the breasts, a rash on or near the nipples and a change in the look of nipples, such as it becoming inverted into the breast (National health service [NHS] UK, 2020).

The likelihood of developing breast cancer results from genetic, environmental, and behavioral/lifestyle components. Numerous risk factors from all of these components contribute to the development of breast cancer and include; age, genetics, diet, oral contraceptives and hormone replacing therapies, menopause, dense breast tissue life style and smoking (Łukasiewicz et al., 2021).

To prevent breast cancer, a number of measures can be taken, such as encouraging women to participate in regular mammograms and screenings accordingly to enable early detection ((Anstey et al., 2017).

2.2.3 Lung cancer

It is characterized by tumors that develop in the lung tissue or the bronchi. Lung cancer is the top cause of mortality among cancer deaths globally. Worldwide, it has consistently been the most frequently detected cancer over the past several decades with over 2.5 million diagnosed cases and age standardized rate of 23.6/100,000 in 2022. In 2022, China, the United States, and Japan reported the greatest number of lung cancer cases (Global Cancer Observatory [GLOBOCAN], 2023).

There are two major categories of lung cancer: small cell lung cancer (SCLC) and non-small cell lung cancer (NSCLC). SCLC is commonly associated with smoking and tends to spread to distant sites at an early stage. Small cell lung cancers are also classified as neuroendocrine tumors. Non-small cell lung cancer (NSCLC) is more common of the two (around 80 to 85 out of 100) and affects both smokers and non-smokers. It is categorized into adenocarcinoma, squamous cell carcinoma, and large cell carcinoma. Smoking cigarettes is the major risk factor for lung cancer. Cigarettes are composed of over 70 carcinogens and there is substantial evidence linking cigarette smoking to lung cancer. Over 80 percent of all diagnosed lung cancer cases are associated with cigarette smoking (Cancer research UK, 2023).

2.2.4 Prostate cancer

The general occurrence of the disease rises with age (Over 80% of men will experience prostate cancer by the age of 80); however, the degree of

aggressiveness of the cancer generally diminishes as individuals' age. It typically grows slowly, is of lower grade, and is relatively benign, causing little effect on survival. Other risk factors include lifestyle factors such as consumption of alcohol and exposure to certain chemicals and medications (National institute of health, 2023).

Prostate cancer typically does not produce symptoms initially. The majority of prostate cancers are detected in their early stages. Early-stage prostate cancer usually does not lead to noticeable symptoms. When symptoms do occur, signs of early-stage prostate cancer may include: presence of blood in the urine, blood in the semen, an increased frequency of urination, a weaker urine stream, and challenges in urination (Mayo clinic, 2024).

2.3 Colorectal cancer

2.3.1 Epidemiology

Colorectal cancer (CRC) is the third most prevalent cancer globally, and it is the leading cause of deaths associated with cancer, representing a major risk to human health. There were over 2 million cases diagnosed in 2022 with an age-standardized rate of 18.4/100,000 globally. Out of this 1.1 million were men and 900,00 were women. The age-standardized rate for men was 22.0 while that for women was 15.2 (World cancer research fund, 2025).

While the prevalence remains elevated in more developed countries, recent trends show either stabilization or a decline, whereas some low- and middle-

income nations have seen a rise in incidence, possibly due to the adoption of more Western lifestyles (IARC, 2019).

Colorectal cancer is responsible for nearly 935,000 fatalities each year. Worldwide, it is among the cancers that are seeing a rise in incidence, attributing for 11% of recorded cancer diagnoses. The age-standardized incidence rate increases more than tenfold from under 50-85 years. Despite progress in colorectal cancer screening that has slightly decreased advanced-stage diagnoses, most cases still occur at later stages. In 2018, the estimated number of global deaths from colorectal cancer was approximately 0.88 million, representing around 1.4% of all deaths and nearly 8.9% of deaths related to cancer, with a more than 30% increase observed over the last 15 years and an anticipated rise of 25% by 2030. Projections suggest that by 2035, the cumulative mortality due to colon and rectal cancer is expected to increase by 71.5% and 60%, respectively (Matsuda et al., 2025).

According to GLOBOCAN, colorectal cancer (CRC) continues to pose an escalating public health challenge in Africa. The continent saw approximately 70,428 new CRC cases and 46,087 deaths attributable to the disease. The age-standardized incidence rate (ASIR) was reported at 8.2 per 100,000 individuals, while the age-standardized mortality rate (ASMR) reached 5.6 per 100,000. Noteworthy is that North Africa had the highest regional ASIRs, trailed by East Africa, indicating disparities in disease burden across regions. A significant gender difference was noted, with males presenting higher

incidence and mortality rates compared to females. Alarming, forecasts indicate a dramatic rise in CRC cases by 2050, with new cases predicted to increase by 139.7% to reach 168,683, and deaths anticipated to rise by 155.2% to 117,568. These statistics underscore the pressing necessity for focused strategies in prevention, early detection, and treatment throughout the continent (GLOBOCAN, 2022).

Data from the Nairobi Cancer Registry shows that colorectal cancer makes up about 6% of all newly diagnosed cancers. Importantly, there has been a notable rise in CRC incidence over the years: 1993–2012: The age-standardized rate (ASR) was 2.9 cases for every 100,000 individuals annually, 2013–2017: The ASR increased to 9.6 cases per 100,000 individuals each year. This pattern highlights the increasing burden of CRC in both urban and rural regions of Kenya (NCI-K, 2020).

Kiegoi location in Nyambene has been identified to be having high cases of colorectal cancer. No studies have however been conducted to determine the disease burden in the area (NCI-K, 2020).

2.3.2 Risk factors

A number of risk factors have been implicated in the etiology of CRC. These are discussed below.

Genetics

Hereditary nonpolyposis colorectal cancer is an autosomal predominant disorder resulting from changes in genes associated with error correction in

DNA mechanisms. Those affected hold approximately 1 in 5 chances of developing colorectal cancer by the age of 50 and about 4 in 5 chances by the age of 85. FAP also follows an autosomal predominant inheritance pattern. The affected population usually starts having polyps in their teenage years, and the polyps at most times progress and cause cancer (Abu-Ghazaleh et al., 2022).

Gender

Colorectal cancer occurs more frequently in men. It is more prevalent in men than women with men having a diagnosis rate of 23.4 per 100,000 and a death rate of 11 per 100,000, while women have rates of 16.2 and 7.2 per 100,000, respectively. Men are more prone to experience higher levels of obesity, and research has shown that increment of 5 kg in weight gained after the age of 18 corresponds to a 9% increased risk of developing CRC. The differences in CRC incidence between sexes might also be related to hormonal factors since estrogen is thought to have a protective effect on colonic epithelium thereby making women less at risk as compared to men (Flores et al., 2025).

Personal history of colorectal cancer or polyps:

Colon polyps, which are precancerous neoplastic growths, are characterized by abnormal tissue extending from the mucous membrane of the colon. Research highlights that close to 95% of colorectal cancers arise from adenomatous polyps. The transition period from adenomatous polyps to invasive adenocarcinoma ranges from 5 to 15 years, with the risk of malignant transformation escalating based on polyp size, the extent of

dysplasia, and the patient's age (Thelin et al., 2015)

Age

Advanced age is a risk factor for most cancers due to the accumulation of risk factors over time and the continuous changes to DNA throughout one's life. The majority of individuals diagnosed with colorectal cancer are over the age of 50. The overall cancer incidence rates increase steadily with advancing age, starting from fewer than 26 cases per 100,000 people in those under 20, rising to around 350 cases per 100,000 among individuals aged 45–49, and exceeding 1,000 cases per 100,000 in those aged 60 and older. The median age at which colorectal cancer is diagnosed is 66 years (NCI, 2025).

The association of colorectal cancer with age is particularly pronounced in developed nations, which report the highest incidence rates. This increase in cases in these countries is linked to longer life expectancies, resulting in a larger elderly population. Screening for colorectal cancer is recommended for adults over 50. Researchers suggest that if this trend persists, the existing screening guidelines should be reassessed (Goodarzi et al., 2019).

Gut micro-biota:

Recent studies examining the micro-biome of patients with colorectal cancer have revealed that alterations in the makeup and activity of the normal gut micro-biota increase likelihood of this cancer type. It was demonstrated that harmful metabolites produced by bacteria could lead to DNA damage, affect cell cycles, activate immune responses, and impair the functionality of the intestinal barrier (Cheng et al., 2020).

Alcohol:

Drinking more than three beverages daily elevates CRC risk by about 40%, with the likelihood rising to 52% for those exceeding three drinks. During the metabolism of alcohol, a number of breakdown products are formed that leads to the creation of mutagenic acetaldehyde (the main metabolite of ethanol), causes a decrease in S-adenosylmethionine that results in epigenetic alterations, inactivates tumor suppressor genes, creates hormonal imbalances, lowers foliate levels, and disrupts retinoic acid metabolism (Keum et al., 2019).

2.3.3 Clinical presentation and staging of colorectal cancer

The symptoms associated with colorectal cancer do not provide a definitive diagnosis, as they exhibit significant overlap with other gastrointestinal conditions. Common clinical signs of CRC include alterations in bowel habits, rectal bleeding, weight loss, abdominal discomfort, and indications of iron-deficiency anemia.

Traditionally, clinical signs vary somewhat depending on the cancer's location: Right-sided colon cancers typically present with abdominal pain, iron-deficiency anemia, a palpable mass in the right iliac fossa, and often manifest later in the disease progression. Left-sided colon cancers are usually characterized by rectal bleeding changes in bowel habits and a palpable mass in the left iliac fossa or during a digital rectal exam (Cancer center, 2021).

The most commonly utilized prognostic framework for colorectal cancer

(CRC) is the tumor-node-metastasis (TNM) system. TNM system is a crucial system used to stage the anatomical extent of colorectal cancer, such as evaluating the primary tumor (T) regional nodal status (N), and absence/presence of distant metastasis (M).

Primary Tumor (T): This category specifies the extent, depth, and size of the invasion of the primary tumor. When the primary tumor cannot be assessed, it is coded as Tx, in the absence of a primary tumor, it is coded as T0, Tis stage is a carcinoma in situ, confined to the mucosal layer with no invasion. Development of tumor invasion is specified in order from least to most severe: T1 describes invasion into the submucosa but not further, T2 describes invasion deeper into the muscularis propria without invading it, T3 describes extension of invasion into the propria, T4a describes penetration through the visceral peritoneum, while T4b describes direct invasion into or adhesion to adjacent organs or structures (AJCC, 2024).

Regional Lymph Node Involvement (N): This group indicates whether and to what extent the cancer has extended to surrounding lymph nodes. If it is not possible to assess nodal involvement, use Nx classification. When there are no regional lymph node metastases, the stage is N0. Nodal involvement is then subdivided according to the number and site of nodes involved: N1a is equal to metastasis to one regional lymph node; N1b indicates two to three nodes are involved, N1c refers to the situation where the tumor deposits are found in the subserosa, mesentery, or non-peritonealized pericolic/perirectal tissues and no nodal metastases can be detected. More extensive nodes are

classified as N2a (four to six nodes with metastases) or N2b (seventeen or more nodes with metastases) (AJCC, 2024).

Distant metastasis (M): This category assesses for metastases at non-regional sites. If metastatic workup cannot be done, the case is classified as Mx. If there is no distant metastasis, M0 is utilized, if metastases are established, sub-classifications are by extent and site: M1a is for a metastasis to a single organ that is distant (e.g., lung, liver, ovary, or non-regional lymph node) without peritoneal involvement, M1b indicates metastases to more than one organ or distant organ, but not the peritoneum, M1c includes peritoneal metastases, with or without other distant metastases (AJCC, 2024).

2.3.4 Diagnostic methods for colorectal cancer

They include visual examination methods and stool based tests. Stool-based tests include high-sensitivity guaiac-based fecal occult blood testing, fecal immunochemical testing, and multi-target stool DNA testing. Stool tests look for the presence of microscopic blood from colorectal cancer or polyps bleeding. Visual examination methods consist of colon capsule endoscopy and flexible sigmoidoscopy (Gude et al., 2023).

Fecal occult blood testing

Blood vessels located at the surface of larger polyps or tumors tend to be delicate and can be easily injured by passing stool. When these blood vessels are damaged, they typically release blood into the stool, which is not

visible. The FOBT is a simple method to check for blood in stool, which may indicate the presence of polyps or colorectal cancer. The FOBT identifies blood in the stool through a chemical reaction. The test uses guaiac, a chemical whose color changes when combined with blood (Grobbee et al., 2022).

Immunochemical Fecal Occult Blood Test (FIT)

FIT employs antibodies to identify hemoglobin in stool samples. It demonstrates greater sensitivity compared to gFOBT while maintaining a similar specificity for recognizing advanced neoplasia. The test operates on the principle that a suitable monoclonal or polyclonal antibody can attach to the intact globin part of human hemoglobin. The iFOBT is vital for the early identification and prevention of colorectal cancer, as prompt intervention can greatly enhance patient outcomes (National Cancer Institute, 2023).

Colonoscopy

In this procedure, the entire colon and rectum are examined using a colonoscope, inserted through the anus into the rectum. While it is an invasive procedure, viewing and removal of the tumor is possible unlike stool-based tests (Juul et al., 2024).

Colon capsule endoscopy (CCE)

It is an effective and safe method for identifying colorectal cancer (CRC) and polyps in a screening context. It was developed as a non-invasive, outpatient approach to examine the entire small intestine without requiring sedation, a day ward bed, or invasive techniques (Gibbons et al., 2023).

2.4 Heavy metals and colorectal cancer

Heavy metals accumulate in human cells, promoting the generation of free radicals, induce genetic mutations in oncogenes and cause damage to genetic material, causing carcinogenesis. Moreover, they can influence critical molecular signaling pathways that regulate cell cycles (Panatta et al., 2021). Multiple epidemiological investigations have examined the relationship between heavy metals and colorectal cancer (CRC) risk as discussed below.

2.4.1 Lead and cadmium

Lead is classified as (2A) carcinogen by the International agency for Research on Cancer [IARC] (Kim et al., 2015). An ecological investigation using population-based CRC data from the Golestan Cancer Registry alongside heavy metal analyses of rice samples from 69 milling factories in northeastern Iran was conducted. Utilizing geospatial statistical modeling (ordinary least squares regression and GIS mapping); it identified a significant positive correlation between dietary exposure to cobalt (Co) and ASR of colon cancer in men. Interestingly, selenium (Se) showed an inverse association, suggesting possible protective effects in areas of higher Se content. Their regression model ($F(4,137) = 38.304$, adjusted $R^2 = 0.77$) included positive coefficients for Co (≈ 120.3) and cadmium (≈ 80.6), and negative coefficients for Se (≈ -6.07), nickel, and zinc. These findings

support the hypothesis that certain heavy metals in staples like rice can influence CRC risk at a population level, reinforcing the importance of soil-to-table food safety monitoring in rural environments (Kiani et al., 2021).

In a study conducted at Heping Hospital, the serum concentrations of 18 heavy metals among 101 CRC patients and 60 healthy controls Using ICP-MS was measured. The results indicated significantly elevated levels of chromium (Cr), arsenic (As), copper (Cu), vanadium (V), tin (Sn), barium (Ba), and lead (Pb) in CRC patients, while selenium (Se) was markedly lower than those in control group. The study found positive correlations between CRC risk and multiple metals, with Se showing a protective, negative correlation. Multivariate logistic regression, adjusted for age, sex, smoking and alcohol consumption, confirmed Cr, Cu, As, and Ba as independent risk factors (Li et al., 2023).

An ecological analysis was conducted across 18 cities in Poland's Silesian province, examining the incidence of colorectal cancer between 2010 and 2014 in relation to long-term cadmium exposure. The study utilized air quality data—specifically average annual cadmium concentrations measured in PM₁₀ particulate matter from 1989 to 2018, and correlated these levels with regional colorectal cancer morbidity. The results demonstrated a statistically significant positive relationship between higher cadmium exposure and increased CRC incidence among both men and women, suggesting that chronic inhalation of cadmium-laden air could constitute a

risk factor for colorectal carcinogenesis (Rogala et al., 2019).

2.4.2 Chromium and Arsenic

Chromium (Cr VI) and arsenic are group 1 carcinogens according to the International Agency for Research on cancer. Various studies have explored the potential role of these two elements in colorectal cancer (CRC) development as discussed below.

A hospital-based case–control study at the Department of Surgery, RG Kar Medical College, Kolkata was conducted. They compared heavy metal concentrations in tissue samples from 50 colorectal cancer patients with those from 100 controls undergoing surgery for nonmalignant conditions. Analysis revealed significantly elevated arsenic and lead levels in malignant tissues compared to control tissues, suggesting that localized accumulation of these metals may be involved in colorectal carcinogenesis in this population (Sarkar et al., 2015)

An investigation of the accumulation of heavy metals in tumor tissue adjacent non-tumor colon tissue, and blood from 180 CRC patients treated at the Precarpathian Clinical Oncology Center was done. Using atomic absorption spectroscopy, they found that tumor tissues contained 9 times more chromium, 8.6 times more lead, and 3.8 times more cadmium than blood ($p < .001$). Even non-tumor colon tissue showed elevated chromium (28.7×), lead (2.8×), and cadmium (3.2×) compared to colon tissue from

healthy individuals. They also developed a prognostic model identifying blood chromium and zinc levels as independent predictors of recurrence-free survival in stage II CRC (Tataryn et al., 2023).

Another study analyzed 104 subjects, including 76 CRC patients and 28 healthy colorectal biopsies, to assess the tissue distribution of metals using inductively coupled plasma atomic emission spectrometry. Their analysis included eight trace elements: Al, Cr, Cu, Fe, Mn, Ni, Pb, and Zn. Cancerous tissue showed significantly higher median levels of chromium and zinc, and lower levels of manganese, tin, and iron compared to non-cancerous tissue ($p < 0.05$), suggesting an elemental fingerprint associated with malignant transformation (Rinaldi et al., 2015).

2.5 Methods of heavy metals analysis

The field of analytical chemistry of heavy metals has experienced notable changes since the 1950s, progressing from basic gravimetric and titrimetric methods to advanced instrumental approaches. This transformation was largely influenced by the growing demand for enhanced sensitivity, improved selectivity, and greater analytical accuracy in both environmental and biological assessments. The advent of Atomic Absorption Spectroscopy (AAS) in the 1960s signified a major breakthrough in heavy metal testing, laying the groundwork for contemporary spectroscopic methodologies. This innovation was succeeded by the development of more sophisticated techniques which improved the capacity for multi elemental analysis.

Atomic Absorption Spectroscopy (AAS)

It is an analytical quantitative and qualitative technique for the measurement of metals and metalloids in samples based on the elements absorption characteristics of spectral lines. The degree to which radiation of a specific frequency is absorbed depends on the length of the path it travels and the concentration of the atoms that absorb it. In AA only one element can be measured at a time therefore making it a lengthy procedure for multi element analysis (Welz & 2018 ; Sperling, 2018).

X-Ray Fluorescence Spectroscopy (XRF)

XRF is a quick, non-destructive technique that employs primary X-rays to excite atoms in the sample, which then emit secondary (fluorescent) X-rays that are characteristic of specific elements. This method is advantageous for screening solid samples (such as soils and sediments), although it has limitations in sensitivity for trace metals and may not be appropriate for biological or food samples without matrix-matched standards (ThermoFisher, 2016).

Electrochemical Methods – Anodic Stripping Voltammetry (ASV)

ASV focuses on concentrating metal ions on an electrode surface, followed by a potential sweep that releases them, producing a current signal proportional to the metal concentration. This technique is sensitive and portable, achieving detection limits in the low ppb range. However, ASV is more susceptible to interferences from organic materials and coexisting ions, and it typically involves fewer target elements (Wang, 2017).

Inductively Coupled Plasma Mass Spectrometry (ICP-MS)

ICP-MS operates by ionizing samples using a plasma source and sorting ions by their mass-to-charge ratio. This technique allows for ultra-trace detection (ng/L to pg/L) and high-volume multi-element analysis (Jarvis, 2016).

The ICP-MS method operates based on mass spectrometric analysis of samples that are ionized in plasma. Achieving the necessary detection limits while ensuring long-term stability and adequate resistance to interference demands a very specific arrangement of equipment. The key elements in an ICP-MS analytical system include:

- High-frequency generator:** The generator's role is to (inductively) generate an alternating magnetic field inside the plasma coil, allowing it to couple with the energy in a gas flow. This process creates the required plasma. Typically, the generator's resonant circuit is tuned to the induction coil and operates at frequencies of 27.12 or 40.68 MHz;
- Plasma torch:** This torch is a multi-walled quartz tube with its outer channel filled with the noble gas argon. The open end of the plasma torch is encircled by the plasma coil or induction coil, which is responsible for transferring energy to the argon flow;
- Plasma coil:** The plasma coil, part of the high-frequency generator, carries an oscillating current that produces an electromagnetic field. This field accelerates charged particles, transferring energy to the argon plasma. The noble gas argon becomes ionized during this process and reaches temperatures between approximately 6,800 and 10,000 K;
- Sample insertion:** A slender injector tube made of quartz, corundum, or sapphire is used to introduce the sample. It injects the sample into the plasma aided by additional argon, breaking chemical bonds in the sample and ionizing free atoms. The method of sample injection

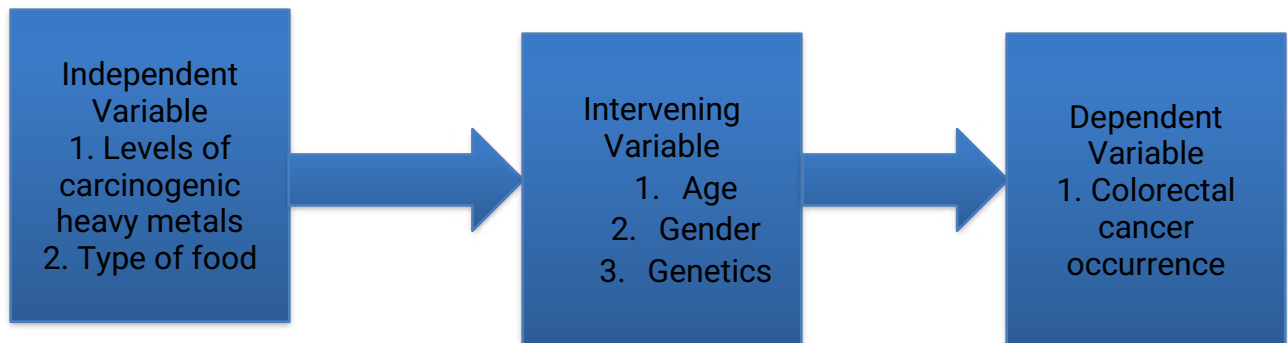
varies based on the sample's state of matter. For liquid samples, the fluid is atomized alongside argon into a fine aerosol, which is then fed into the injector tube. Gaseous samples can be connected directly to the injection tube, while solids must first be converted into gas and then introduced with a carrier gas flow; Interface: The interface must carry the ionized sample from the plasma into the high-vacuum region of the mass spectrometer. Simultaneously, it directs the ion beam to the ion optics, where extraction lenses collimate it. Two conical pinhole apertures, referred to as cones, are employed to separate vacuum regions; Interference management: In ICP-MS, interference is mitigated through the use of collision gases and/or reaction gases. In collision mode, polyatomic interferences are eliminated by reducing kinetic energy or through dissociation. In reaction mode, interfering ions and polyatomic ions are transformed into new, non-interfering products. Ion optics: The ion optics consists of a lens system that focuses the ion beam and channels it into the mass spectrometer; Mass filter: The mass filter typically has a quadrupole shape, made up of four parallel rods. These produce an alternating magnetic field that steers the ions along spiral paths. A critical performance parameter of ICP-MS instruments is the quadrupole scan rate, indicating the speed of the measurement process. High-performance systems can achieve scan speeds exceeding 5,000 amu/s; Detection system: At the end of the mass filter is a detection system that generates a measurement signal corresponding to the frequency of the ions detected. Typically, secondary electron multipliers and Faraday detectors are employed in practice (Analytik & Jena, 2020).

For this study, ICP-MS will be employed.

2.6 Conceptual Framework

Figure 2.1

Conceptual framework



Heavy metals can be introduced into the environment through either natural phenomena such as weathering and leaching or through anthropogenic activities. Once introduced into the environment these metals can be taken up by the plants from soil and water. Foods grown in contaminated environment take up the heavy metals and accumulate them, introducing the metal contaminants into the food chain. Depending on the plants morphological features and characters, some plants may have a higher tendency to accumulate heavy metals than others. Humans become exposed to these metals upon consumption of these contaminated foods, and the metals undergo bioaccumulation in various parts of the body. The metals then cause a number of actions including somatic mutations, increased production of reactive oxygen species and epigenetic changes all of which promote carcinogenesis and lead to development of colorectal cancer. Over time and age, people are exposed to these heavy metals and other contaminants leading to a heightened risk of developing cancer with increased age.

2.7 Research gaps to address

- a. Lack of documented data on colorectal cancer prevalence, morbidity and mortality in Kiegoi. Many people in this region are being diagnosed with colorectal cancer, but no concrete figures exist on the actual prevalence of CRC. This study will undertake to establish the actual prevalence of CRC by review of hospital records.
- b. Limited studies about infiltration of heavy metals in foods consumed

in Kiegoi. That many people in this geographical region are being afflicted with colorectal cancer points out to possible environmental carcinogens. Studies investigating the levels of carcinogenic heavy metals in foods in Kiegoi are generally limited. This study will therefore investigate the presence of heavy metals in commonly consumed food crops in Kiegoi.

- c. Insufficient documented data on the association of heavy metals from dietary sources with colorectal cancer prevalence in Kiegoi. No studies have been conducted to understand the impact of heavy metals from dietary sources on the etiology of colorectal cancer in Kiegoi. This research will therefore set out to establish the relationship if any between the two.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter contains the methods used in data collection.

3.2 Research Design

This study sought to determine the association between heavy metals and colorectal cancer. To achieve this, a correlational cross sectional study design was utilized to analyze the relationship between variables by observation. This involved examination of clinical data from cancer registry at Meru Teaching and Referral Hospital (2018-2024) to determine prevalence and elemental analysis of staple foods using ICP-MS.

3.3 Target population

This study was conducted in the Kiegoi location. The total adult population of Kiegoi according to the Kenyan National Bureau of Statistics is 16,514 as of December 2024. Patient files of colorectal cancer patients were obtained from Meru Teaching and Referral Hospital Oncology unit registry. For a record to be eligible it had to meet the inclusion criteria. The inclusion and exclusion criteria used were:

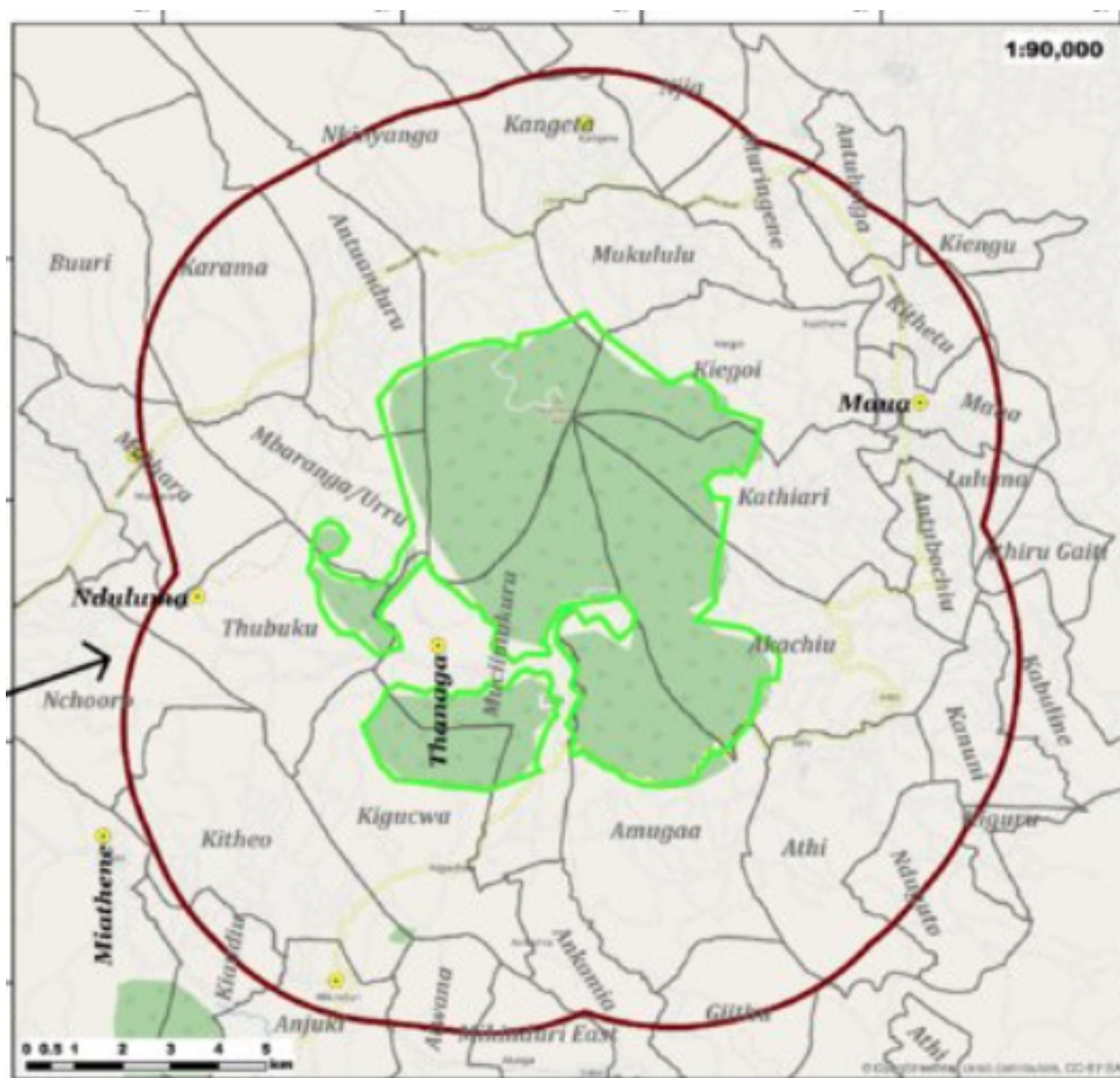
Inclusion criteria: Clinically confirmed active adult colorectal cancer patients from Kiegoi recorded in the hospitals' database in the period January 2018

to December 2024.

Exclusion criteria: CRC patients who were not from Kiegoi, inactive status/deceased or had other underlying colorectal conditions.

Figure 3.1

Map of Nyambene showing Kiegoi



Source: <https://www.mindat.org/feature-11881456.html>, January 2025

3.4 Sampling techniques and sample size determination

Food samples (maize, beans, potatoes and arrowroot) were collected via a stratified random sampling across Kiegoi's five agro-ecological zones. This involved plotting of the five agro-ecological zones on a map and then randomly collecting each of the four foods from a different location within each of the zones. Yamane's formula was used in determination of the sample size of the foods to be analyzed (Lund, 2023).

$$n = N / \{1 + (N * e * e)\}$$

Where n=Sample size

N= population size

e= Margin of error

In Kiegoi, there are five (n=5) agro-ecological zones. Using a margin of error of 5 percent and a population size of 5

$$n = 5 / \{1 + (5 * 0.05 * 0.05)\}$$

We get a sample size of 5, which is one sample per food from each of the five agro-ecological zones. A power analysis was conducted to justify the number of samples to be collected for heavy metals levels comparisons by one way ANOVA.

$$\text{Power} = 1 - \text{Fncf} (F_{\alpha}; df_1; df_1, df_2, \sqrt{f})$$

Where $df_1 = k - 1$, $df_2 = k (n - 1)$ and $f_{\alpha}; df_1, df_2$ is the critical f value at level α .

Cohen's F is a standardized measure of effect size for ANOVA.

The conventional type I error was set at $\alpha = 0.05$ and desired $1 - \beta = 0.80$. The power analysis (one way ANOVA, $k=5$) for a large effect $f=0.40$ yields: $n=11$ samples with a power 0.80.

However, collecting 15 samples per zone was not feasible given logistics and budget constraints (high cost of analysis per sample) we therefore opted to collect a total of 5 samples in triplicates per crop which would give a better power analysis.

The sample size of patient files to be reviewed was determined using Cochran's formulae (Bolarinwa, 2020).

$$n = \frac{\{Z^2 \cdot p \cdot (1-p)\}}{e^2}$$

Where n = Sample size

Z = Z score (confidence level)

P = estimated population prevalence

e = Estimated margin of error

Taking an error of 5 percent, a z score of 1.96 and a global CRC prevalence of 10 %, the sample size is

$$n = \frac{1.96^2 \cdot 0.1 \cdot 0.9}{0.05^2}$$

We get a sample size of 139. After reviewing of patient files a total of active 200 colorectal cancer cases of patients from Kiegori were identified, and used giving a margin of error of approximately 4.16 % for an observed prevalence of 10% (95 % CI). Including the entire available sample therefore

increases precision relative to the initial calculated minimum.

3.5 Hospital records review

Before data collection, enumerators underwent training on how to use the data collection form, ethical guidelines and identification of legible and eligible records. Administrative approval to collect data at the oncology unit was sought from the hospital management. Patient files at the oncology registry screened, to identify eligible and ineligible records. Every identified colorectal cancer (CRC) case was evaluated by the research team, using a structured questionnaire. Each data entry received a distinct patient study code (CRC001, CRC002 etc.) to maintain confidentiality during the analysis process. All gathered data was documented in a pre-structured spreadsheet that had fields reflecting the questionnaire.

3.6 Elemental analysis

3.6.1. Inductively coupled plasma mass spectrometric analysis

An elemental analysis of cadmium, chromium, lead, arsenic, and mercury in the selected food samples was performed with an Agilent 7900a ICP-MS coupled with mass Hunter[®] version 4.3 software. The Agilent 7900a was equipped with standard nickel sampling and skimmer cones having orifice diameters of 1.0 mm and 0.4 mm, respectively, along with a standard glass nebulizer, a quartz spray chamber chilled to 2 °C, and a quartz torch that featured a 2.5 mm injector.

An Agilent ASX-520 auto sampler was used to transfer the samples, which were contained in 50 mL vials, to the ICP-MS. The system included a 4th generation collision/reaction cell and an octopole reaction system (ORS) that enabled efficient elimination of polyatomic interferences using Helium (He) mode. Before each analysis, the inductively coupled plasma mass spectrometry (ICP-MS) was calibrated with an aqueous multi-element standard solution containing Li, Sc, Ge, Rh, In, Tb, Lu, and Bi, all diluted in 10% HNO₃ to ensure reliable sensitivity (Hassan et al., 2021).

The operating conditions for the ICP-MS analysis are outlined in Table 3.1.

Table 3.1

The operating conditions for the ICP-MS analysis

Plasma Conditions	Flow rate
Radio frequency power supply	1.55 Kw
Plasma argon	15 L/min
Auxiliary argon	0.9 L/min
Nebulizer argon	0.9 L/min
Collision gas	3.9 mL/min

3.6.2 Reagents, materials and chemicals

Acids of analytical grade that is hydrochloric acid, nitric acid and perchloric acid obtained from Griffchem fine chemicals were used for sample digestion. All solutions were prepared with analytical reagent-grade chemicals and ultrapure water.

3.6.3 Sample preparation

3.6.3.1 Acid digestion

Acid digestion was done according to the procedure adopted from (US EPA 2014). A gram of peeled, dried, and crushed arrowroot sample was weighed and placed into a 500 mL Kjeldahl flask. Next, 10 mL of concentrated nitric acid was added, and the mixture heated in a digestion block (at 180 degrees) until the vigorous reaction subsided. 10 mL of hydrochloric acid was then added and the mixture heated until it was light colored and the dense fumes disappeared. 10 mL of perchloric acid was finally added and the mixture heated (at 180 degrees) until dense white fumes are visible. Afterwards the mixture was allowed to cool and filtered using a filter paper. The filtrate was transferred to a 50 mL volumetric flask and filled to volume with distilled deionized water. The procedure was repeated for the other food samples.

After digestion the samples were subjected to ICP-MS analysis.

3.6.2 Calibration and determination of unknown concentration of analyte (Working curve method)

Calibration was performed to assess how the instrument's signal reacts to variations in concentration. Known concentration working standard solutions, along with a multi-element solution with ascending concentrations of each target element, were utilized. A calibration curve was created by plotting the response (counts per second) against concentration, allowing for the determination of unknown analyte concentrations based on the calibration curve.

3.7 Data Analysis and interpretation

Data were double entered into Excel, validated, then imported into SPSS version 26. Crude and age standard rates were computed using WHO standard population. Descriptive statistics summarized demographics and metal concentration data.

3.8 Data presentation

Data were summarized in the form of proportions and frequency tables for categorical variables. Continuous variables were summarized using mean, median, mode and standard deviation. ANOVA was used was used to test for significance of associations between the heavy metals levels in different crops.

3.9 Ethical considerations

Ethical clearances were sought from the KeMU ethics committee, NACOSTI

and the hospitals before data collection to ensure the research was conducted according to the required ethical guidelines. The use of offensive, discriminatory, or other unacceptable language was avoided in the formulation of questionnaire and data collection. Privacy and anonymity of patients was of paramount importance. Strict confidentiality was upheld throughout: no names, identification numbers, or personal contact information was documented and data was anonymized immediately upon entry collection. Collected data was stored in files secured by passwords. Findings were also shared with participating hospital for the purpose of healthcare planning.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This study set out to determine the prevalence of colorectal cancer in Kiegoi location of Nyambene, assess the levels of five carcinogenic elements in commonly consumed foods in Kiegoi using ICP-MS and determine the correlation between the two. The results obtained are presented using tables and figures below.

4.2 Calibration and limits of measurements

The performance characteristics of the method, including regression equations for the best-fit line, the correlation coefficient value, percentage recovery, and limits of detection (LOD), were assessed and the results obtained are presented below. All the laboratory blanks were below the detection threshold.

Table 4.1

Calibration coefficients, limits of detection and limits of quantification

Element	Molecular mass	R ²	LOD (ppb)	LOQ (ppb)
As	75	0.9998	1.671798	5.572661
Cd	111	0.9999	1.363076	4.543587
Cr	52	0.9968	0.000673	0.01500
Hg	201	0.9985	4.726475	15.75492
Pb	208	0.9969	6.703868	22.34623

4.3 Colorectal cancer trends and prevalence

4.3.1 Colorectal cancer demographics and prevalence

The results on demographics of the respondents for this study are presented in the table and figure below.

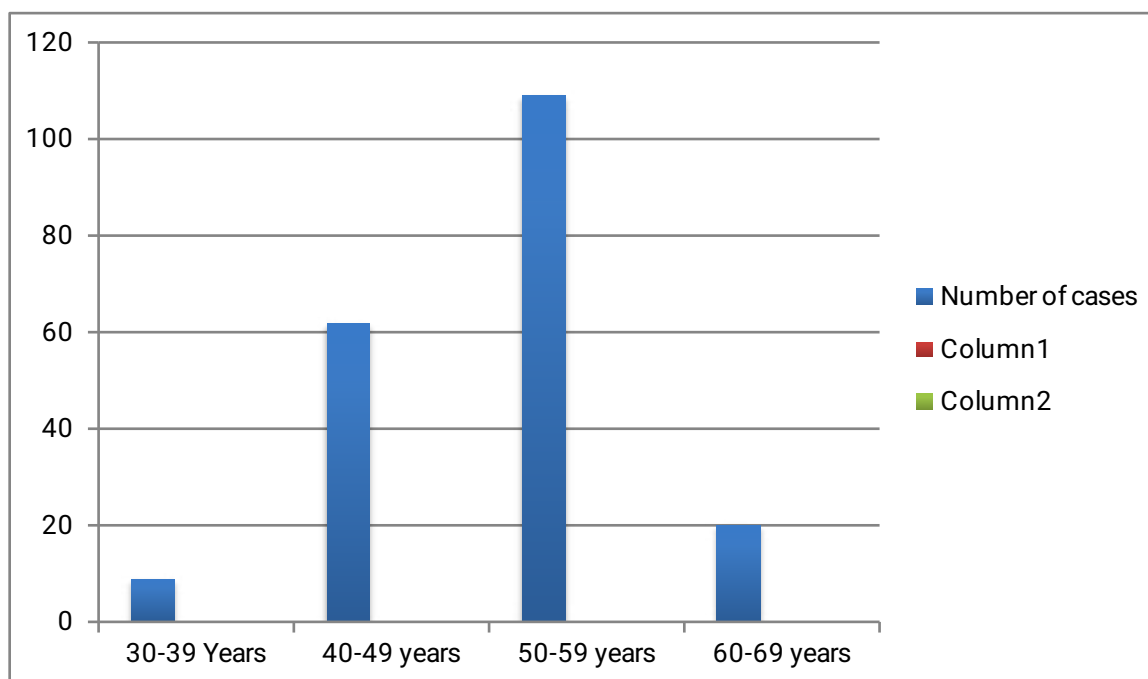
Table 4.2

Demographics

Variable	Frequency
Age (Mean, Median)	51.27, 51
30-39	9 (4.5%)
40-49	62 (31%)
50-59	109 (54.5%)
60-69	20 (10%)
Gender	
Female	84 (42%)
Male	116 (58%)

Figure 4.1

Age group distributions of CRC Cases



The crude prevalence and age standardized rate of colorectal cancer in Kiegori was determined and is presented in table 4.3 below.

Table 4.3:

Crude prevalence of CRC

Age group	CRC cases	Estimated population	Crude Prevalence per 100,000
30-39	9	4128.5	218
40-49	62	4128.5	1502
50-59	109	4128.5	2640
60-69	20	4128.5	484
Overall	200	16514	1211

From the above crude prevalence age standardized rate (ASR) was determined to allow for comparison of rates.

Table 4.4*Age standardized rates of CRC*

Age group	Rate per 100,000	WHO weight	Weighted rates
30-39	218	0.15	33
40-49	1502	0.14	210
50-59	2640	0.12	317
60-69	484	0.08	39
ASR			599

From the results, the majority of the study participants were males with 116 cases (58%), while female cases identified were 84 (42%), translating into a male-to-female ratio of approximately 1.38:1. Findings from this study indicate that colorectal cancer was more prevalent in men compared women, aligning with general epidemiological trends often reported for colorectal cancer.

According to White et al. (2018) the overall incidence of colorectal cancer was higher in men (male to female ratio was 1.5 to 1) compared to women. Gangireddy et al. (2018) found the overall incidence of CRC was generally higher in men than women with a male to female ratio of 1.3 to 1.

According to Yang et al. (2020) this higher male predominance can be attributed to biological explanations as sex-specific differences in hormonal milieu, most prominently the hypothetical protective-effect for estrogens on colonic epithelium. Estrogen receptor beta (ER β) is the most prevalent estrogen receptor in the colonic epithelium and is frequently lower in colorectal cancer. ER β can influence the immune response in the colon, suppressing the synthesis of pro-inflammatory agents and reducing the number of inflammatory cells attracted to the site, both being frequently encountered in colorectal cancer. It can also induce the cellular suicide (apoptosis) of harmed or dysfunctional colonic cells, prior to them being capable of multiplying and eventually developing into cancer.

The age group analysis indicates that most cases of colorectal cancer in this population are between 40-60 years. The mean age of the study participants was 51.27 years and ranged from 35-65 years. The analysis of age at diagnosis

reveals that the majority of colorectal cancer cases fall within the older age brackets. Specifically, the highest number of cases (109) is observed in the 50-59 years age group representing the peak incidence. This is followed by 62 cases in the 40-49 years age group, and 20 cases in the 60-69 years group. A smaller number of cases, 9, are found in the 30-39 years group.

This distribution is broadly consistent with previous studies that found that incidences of colorectal cancer to be prevalent among the elderly. Li et al. (2024) reported that the elderly (50-60 years) accounted for 13.7 % of colorectal cancer incidences. Alam et al. (2025) found that 85 % of patients with colorectal cancer in Brazil were over 50 years of age.

Crude CRC incidence in Kiegoi was 1211 per 100,000 populations. The highest prevalence (2640 per 100,000) was recorded in those aged 50-59 years. This was followed by 40-49 years with 1502 per 100,000, then 60-69 years with 484 per 100,000 and finally 30-39 years with 218 per 100,000. The age specific standardized rate using WHO world populations was 599. According to GLOBOCAN, data from the Nairobi cancer registry showed that the ASR was 22 per 100,000 in 2022. The relatively higher prevalence from this study can be attributed to the smaller population size of Kiegoi compared to Nairobi.

Globally countries with the highest ASR for CRC include Hungary (51.2 per 100,000), Denmark (48 per 100,000) and South Korea (44.5 per 100,000) (GLOBOCAN, 2022).

A 95 percent confidence interval was performed on the prevalence data and the findings are presented below.

Table 4.5

95 % confidence level testing

Age group	CRC	prevalence	95 CI
	per 100,000		
30-39	218		75.73 – 360.26
40-49	1502		1130.76 – 1872.75
50-59	2640		2151.13 – 3129.24
60-69	484.		272.64 – 696.23
Overall	1211.		1044.27 – 1377.92

For the 30-39 years age group the confidence interval was 75.73 to 360.26 against a prevalence of 218 per 100,000. The 40-49 years age group had a confidence interval of 1130 to 1872 with a prevalence of 1502. Individuals' aged 50-59 had a prevalence of 2640 and confidence interval of 2151 to 3129. For the 60-69 the confidence interval was 272 to 696 against a prevalence of 484.

The findings confirm that CRC prevalence increases markedly from young adulthood to middle age, peaking in the 50–59 year age group. The steep rise in prevalence between the 50–59 age group could mirror the gradual accumulation of CRC risk factors with age, in accordance with established international patterns.

The wide confidence intervals, particularly for the 30–39 and 60–69 age groups, reflect greater uncertainty and possibly fewer cases. However, the results generally emphasize the need for CRC screening and preventive interventions to be focused particularly on those 40 years and older, with extra vigilance for the 50–59 age group, where the burden is highest.

4.3.3. Clinical presentations

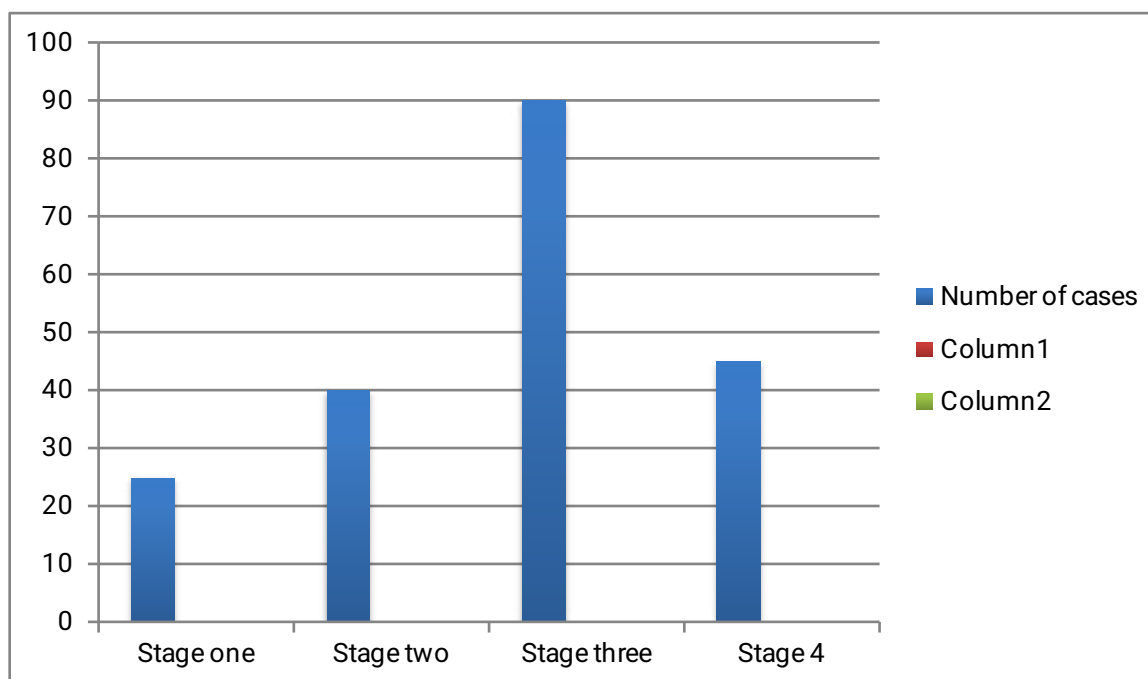
The clinical presentations and Tumor Node Metastasis (TNM) staging of the respondents in this study are presented in table 4.6.

Table 4.6*Clinical Parameters*

Variable	Frequency	Percentage
Clinical presentation	n=200	
Blood in stool and abdominal pain	105	52.5
Anemia and tiredness	57	28.5
Rectal bleeding	36	18
Other clinical presentations	2	1
TNM staging	n=200	
Stage 1	25	12.5
Stage 2	40	20
Stage 3	90	45
Stage 4	45	22.5

Figure 4.2

TNM staging presentation



All of the subjects presented with more than one symptom. The common symptoms were blood in stool in 105 patients (52.5%), abdominal pain in 57 patients (28.5 %) and rectal bleeding in 36 patients (18 %). Intestinal obstruction and weight loss were less common symptoms.

This aligns with findings from other research conducted that found blood in stool and rectal bleeding to be the most prevalent symptoms (Briggs et al., 2024; Holtedahl et al., 2021; Skalizky et al., 2023). Bleeding is the primary symptom in the initial stage of colorectal cancer and requires prompt and thorough investigation. However, based solely on the presence of bleeding, it remains a diagnostic challenge to differentiate between a benign anal condition and a serious underlying colorectal issue.

TNM staging revealed stage 3 has the highest number of cases at 45%, followed by Stage 4 with 22.5 %, then stage 2 with 20 % and stage 1 with 12.5 %. This is in line with other research publications that found stage 3 and 4 to be more prevalent (Andrew et al., 2018; Dantas et al., 2022; Wassie et al., 2022).

Late diagnosis in this population is likely to be influenced lack of awareness about the disease, limited access to healthcare facilities, and the absence of screening programs in this area.

4.4 Heavy metals contents of analyzed samples

4.4.1 Heavy metals levels in analyzed food crops

Four foods were sampled that is arrowroot (CA250425-CA250429), beans (CA250430-CA250434), maize (CA250435-CA250439) and potatoes (CA250440-

CA250444).

Table 4.7*Content of selected heavy metals in foods from Kiegoi*

Sample code	Concentration (mg/kg)				
	Mercury	Lead	Cadmium	Arsenic	Chromium
CA250425	0.145336	0.143292	0.011044	0.374537	19.212
CA250426	0.129783	0.173102	0.0268673	0.4502443	13.923
CA250427	0.1978437	0.168458	0.025267	0.532177	21.836
CA250428	0.106552	0.2078253	0.020052	0.36559	21.665
CA250429	0.192434	0.111385	0.019873	0.5174987	24.329
CA250430	0.2536027	0.257792	0.026737	0.4317143	16.136
CA250431	0.280179	0.221366	0.033701	0.40025	20.163
CA250432	0.1445513	0.243147	0.026258	0.5274357	48.354
CA250433	0.1751107	0.18839	0.029332	0.4584647	34.364
CA250434	0.2434327	0.231919	0.0312598	0.6037153	15.786
CA250435	0.136583	0.13786	0.0357343	0.6121767	31.563
CA250436	0.1766263	0.167826	0.0310413	0.7683457	35.027
CA250437	0.2120987	0.243966	0.0310207	0.6247547	31.869
CA250438	0.221014	0.23735	0.0421373	0.3687143	19.883
CA250439	0.155501	0.257235	0.0310767	0.5203463	33.828
CA250440	0.0695285	0.165267	0.0191647	0.585673	17.252
CA250441	0.1411533	0.232331	0.0096273	0.6549077	34.887

CA250442	0.103301	0.209018	0.019957	0.3339623	27.848
CA250443	0.1630197	0.191708	0.017404	0.47777	13.684
CA25044	0.202097	0.063374	0.0254143	0.3030963	14.383

The mean concentration of each heavy metal across the samples provides an initial overview of contamination intensity. Mercury's range was 0.0695-0.280 mg/kg and its mean concentration was 0.1725 mg/kg, which was well above the permissible limit of 0.02 mg/kg. Lead had the ranges 0.063-0.2577 mg/kg, with a mean of 0.1932mg/kg was marginally below the permissible limit of 0.2 mg/kg but still posed colorectal cancer risk due to the high number of samples grossly contaminated with this metal. Cadmium had the ranges 0.0096-0.035 mg/kg, with a mean of 0.0256 mg/kg, which was way below the permissible limit and therefore posed no colorectal cancer risk. Arsenic had the ranges of 0.3030-0.7683 mg/kg with a mean of 0.4886 mg/kg, which was slightly under the regulatory limit in food indicating borderline colorectal cancer risk. Chromium had the ranges 13.68-48.35 mg/kg, with a mean of 24.80 mg/kg, which was way above the regulatory limit of 1 mg/kg.

Findings from this study are similar to those by Oyugi et al., (2024) who analyzed heavy metals in Khat samples from Meru County and found the mean levels of Pb (32.36 mg/kg), Cd (7.81 mg/kg), and Cr (15.98 mg/kg) exceeded WHO permissible limits. Ireri et al., (2014) also found the levels of Khat from Nyambene and Meru had levels of Pb (0.3 mg/kg) and Cr (1.7 mg/kg) above the WHO recommended safety limits therefore posing health risks. A study by Damana et al., (2024) on the levels of Khat and soil in Ethiopia also found the levels of Cd (0.38 mg/kg) and Cr (1.69 mg/kg) exceeded the FAO/WHO permissible limits.

Overall mercury and chromium exhibited the highest contamination rates with

all 20 samples exceeding permissible limits, lead and arsenic had 10 contaminated samples each exceeding the permissible limits while cadmium levels in all samples were below the permissible limits. Many of the samples therefore pose numerous health risks if consumed since they contain very high levels of metals.

4.4.2. Comparison of the food heavy metals content against regulatory limits

Each of the food types (Beans, maize, arrowroot and potatoes) was compared to WHO/FAO and KEBS safety thresholds using one sample t test to determine whether the observed means significantly differ from the regulatory limits. The results (p values) obtained are presented in table 4.8 below.

Table 4.8

Comparison of heavy metals content against regulatory limits

Food type	Pb	Cd	Hg	Cr	As
Beans	0.072	9.15×10^{-7}	0.0014	0.0148	0.6894
Maize	0.726	7.20×10^{-6}	0.0006	0.0041	0.2971
Potatoes	0.40	5.67×10^{-6}	0.0073	0.0079	0.6948
Arrowroots	0.071	8.80×10^{-6}	0.0016	0.00041	0.2086

The results revealed significant deviation for Mercury and chromium at 0.05 significance levels that is the levels were significantly above permissible levels in every food sampled raising concerns about their potential health implications. The p value of cadmium was close to 0.0001 in all foods indicating very strong evidence of cadmium levels being significantly below regulatory thresholds. Arsenic levels did not significantly exceed the regulatory limits though several samples were close. Lead showed borderline excess in beans and arrowroots suggesting potential excess but not statistically significant at the 5 %level.

4.4.3 Comparison of the levels of heavy metal contamination across different selected foods

A one-way ANOVA was conducted for each metal to determine whether their concentrations significantly differed across the four sampled foods. The results are presented in table 4.9 below.

Table 4.9

Heavy metals contaminations across foods

Metal	F statistic	P value
Mercury	2.98	0.062
Lead	2.19	0.129
Cadmium	10.65	0.0004
Arsenic	1.14	0.362
Chromium	1.33	0.300

The results revealed that cadmium concentration varied significantly across the different foods ($p=0.0004$ $f =10.65$) indicating that certain foods tend to accumulate cadmium more than others probably due to differences in root systems, uptake mechanisms or soil conditions.

For the other four heavy metals no statistically significant differences were found in concentrations across the four foods. This suggests that contamination is uniform across all the sampled foods possibly due to soil contamination. While statistically not significant, Mercury p value was borderline ($p=0.062$), which may indicate a trend toward variation that could be confirmed with a larger sample size.

4.5 Association between heavy metals and colorectal cancer

A multivariate logistics regression was conducted to examine the association between average heavy metal concentrations (Mercury, lead, cadmium, arsenic and chromium) in four foods and age-standardized rates of colorectal cancer in Kiegoi. The regression categorized foods as either high risk or low risk based on their ASR contribution. The results are presented in table 4.10 below.

Table 4.10

Association between heavy metals and colorectal cancer

Predictor	Coefficient (β)	Odds ratio (OR)	95 % CI for OR	P values
Mercury	+1.25	3.49	1.55 – 7.89	0.003
Lead	+2.87	17.66	8.92 – 34.96	$5.26 * 10^{-16}$
Cadmium	-0.45	0.64	0.31 – 1.32	0.22
Arsenic	+0.91	2.48	1.10 – 5.60	0.014
Chromium	+0.06	1.06	0.90 – 1.30	0.71

Lead demonstrated the strongest association with elevated colorectal cancer risk (OR=17.66, β +2.87, 95% CI 8.92-34.96). This is consistent with previous epidemiological studies that associate chronic lead exposure with carcinogenic effects. Mercury also showed a significant positive association (OR=3.49, β +1.25, 95% CI 1.55-7.89) suggesting that even at low levels mercury may contribute to carcinogenesis possibly due to oxidative stress and DNA damage. Arsenic demonstrated a moderate increase in risk (OR=2.48, β +0.91, 95% CI 1.10- 5.60) aligning with previous studies that link inorganic arsenic to gastrointestinal and colorectal malignancies. Cadmium had a negative coefficient (OR 0.64, β -0.45, 95% CI 0.31-1.32) suggesting a possible inverse relationship. This is due to the consistently low detected levels of cadmium that was below regulatory limits in all food samples collected from the study area (0.0256 mg/kg). Chromium showed a very slight effect (OR=1.06, β +0.06, 95% CI 0.90-1.30) suggesting a minimal contribution to colorectal cancer risk. Njale et al. (2024), Liao et al. (2015), Vagnoni et al. (2024) and Huang et al. (2025) found a positive association between risk of cancer and concentrations of As, Cr, Hg and Pb. The inverse relationship of cadmium in this study is attributed to the relatively low levels of cadmium in all food samples obtained that were below permissible limits by FAO/WHO in foods.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This study sought to evaluate the association between dietary exposure to carcinogenic heavy metals and the development of colorectal cancer in Kiegoi, Meru County, Kenya. The objectives of the study were achieved through statistical analysis of the data from the cancer registry and laboratory analysis of the heavy metal content in locally consumed foods.

5.2 Conclusions

5.2.1 Prevalence and trends of colorectal cancer

The analysis of crude and age-standardized rates (ASR) of colorectal cancer in Kiegoi shows an alarming trend in epidemiology. Although cancer surveillance in rural Kenya is not well developed, available health records and population data show a general increase in colorectal cancer prevalence, over the years, especially among middle-aged and elderly individuals.

The increased ASR in Kiegoi area also indicates that colorectal cancer not only occurs but is also underreported. These findings corroborate the necessity of establishing localized surveillance programs and developing diagnostic capacity in rural areas like Kiegoi.

5.2.2 Heavy metal contamination levels in selected foods

Elemental analysis of the four staple food samples, revealed the presence of all

five targeted heavy metals. Mercury and Chromium were much above regulatory limits in all food types sampled, with very significant p-values ($p < 0.01$), posing a public health risk. Lead was above threshold in Beans and Arrowroots, but only just so ($p \approx 0.07$). Cadmium levels were well below the threshold in all foods ($p < 0.00001$), indicating very small exposure through this route. Arsenic had no statistically significant deviations, but concentrations in individual samples approached the threshold. These results indicate unacceptable contaminant levels in key food sources.

5.2.3. Comparison of Heavy Metal Levels Among Foods

Analysis of variance (ANOVA) revealed that cadmium content differed considerably between foods ($p = 0.0004$), where beans and maize had a tendency to absorb greater amounts of this metal. This would suggest that certain crops have a greater soil uptake affinity for specific metals, based on plant variety, root architecture, and native soil chemistry. On the other hand, Mercury, Lead, Arsenic, and Chromium were not meaningfully different by crop, which suggests environmental contamination as opposed to crop-specific contamination.

5.2.4 Association between heavy metals contamination of foods and Colorectal Cancer Risk

Multivariate logistic regression analysis indicated a significant statistical association between colorectal cancer risk and exposure to Lead, Mercury, and Arsenic. Lead was the most powerful predictor (Odds Ratio = 17.66), reinforcing

its established status as a carcinogen. Mercury (OR = 3.49) and Arsenic (OR = 2.48) also showed high risks. Cadmium, as toxic as it is, was not significantly related to colorectal cancer within this model, perhaps because it is present only at low concentrations within the food that was studied. Chromium was weakly associated (OR = 1.06), possibly due to the exposure to Chromium (III), a less toxic compound, rather than the more toxic Chromium (VI). These findings suggest that long-term dietary exposure to some heavy metals maybe a significant risk factor for the development of colorectal cancer in Kiegoi.

5.3 Recommendations

- 1. Public health surveillance and screening.** The National Cancer Institute Kenya and the Meru county government health department should strengthen cancer surveillance and screening programs in Kiegoi to identify colorectal cancer early enough especially for high-risk groups such as men. This can be achieved by deployment of mobile cancer screening clinics, which would greatly enhance access to cancer screening facilities. Currently the only available facility for cancer screening is at Meru Teaching and Referral Hospital, which limits the accessibility of these services. Community health promoters can also be trained on the early warning signs of colorectal cancer and they can then disseminate this information to the community members. This will enable prevention and also prompt and timely management of the disease hence better outcome (NCI-K, 2022).
- 2. Environmental monitoring and soil remediation.** National Environmental

Agency in collaboration with the county government should conduct routine monitoring and testing of soil and water sources in Kiegoi for heavy metal contamination to identify the sources of heavy metal infiltration of foods (Muniafu et al., 2022).

3. **Phytoremediation strategies.** Residents of Kiegoi should be encouraged to cultivate ornamental phytoremediation plants. These plants take up heavy metals from the surrounding environs into their tissues thereby reducing the concentrations of these heavy metals in the environment. As they are ornamental these plants are not part of the food chain and pose little risk in the dietary exposure pathway (Kafle et al., 2022).

5.4 Further research

- i. Studies incorporating larger sample size of foods and more food varieties per zone should be conducted. Larger sample sizes provide power to detect differences in heavy metals concentrations across the various foods and zones.
- ii. Studies incorporating a longitudinal research design to establish causality should be conducted as this study utilized a correlational design. These studies can incorporate use of biomarkers in precision risk assessment.
- iii. Chemical speciation should be carried out to determine the chemical forms of the heavy metals present in the area since some forms of metals such as chromium VI are more toxic than chromium III

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APPENDIX

Appendix 1: Hospital record review data collection form

Facility Name: _____

Location: _____

Reviewer Name: _____

Date of Data Collection: __/__/____

Study Period: From __/__/____ to __/__/____

Section 1: Patient

Demographics (✓ Tick or fill
where applicable)

|-----|-----|

| Patient ID (Anonymized) | _____ |

| Age (Years) | _____ |

| Gender | ☐Male ☐Female ☐Other |

| Residence (County/District) | _____ |

| Date of Diagnosis (DD/MM/YYYY) | __/__/____ |

Section 2: Diagnosis Details

| Tumor Location | ☐Proximal Colon ☐Distal Colon ☐Rectum ☐Unknown

Section 3: Treatment Information

| Variable | Data Collected |

|-----|-----|

| Treatment provided | ☐Surgery ☐Chemotherapy ☐Radiation ☐Palliative Care ☐No Treatment
|

| Treatment Outcome | ☐Recovered ☐Ongoing ☐Recurrence ☐Deceased |

| Date of First Treatment (DD/MM/YYYY) | __/__/____

Section 4: Risk Factor Information (If Available)

| Risk Factor | Present?|

|-----|-----|

| Family History of Colorectal Cancer | ☐Yes ☐No ☐Unknown |

| Smoking History | ☐Yes ☐No ☐Unknown |

| Alcohol Consumption | ☐Yes ☐No ☐Unknown |

| Diet (High red meat/low fiber) | ☐Yes ☐No ☐Unknown

Section 5: Additional Notes

(Any missing data, challenges, or observations)

Reviewed By: _____

Signature: _____ Date: __/__/____



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DIRECTORATE OF POSTGRADUATE STUDIES

Our Ref: KeMU/NACOSTI/PHT/06/2025

12th May, 2025

Commission Secretary
National Commission for Science, Technology and Innovations
P.O. Box 30623-00100
NAIROBI

Dear Sir/Madam,

RE: ONDUSO BRIAN MOINDI-PHT-3-0180-1/2024

This is to confirm that the above named is a bona fide student of Kenya Methodist University, in the Department of Public Health, Human Nutrition and Dietetics, undertaking a Master's Degree in Public Health. He is conducting research on; *"Effect of Carcinogenic Heavy Metals in Food Crops Grown and Consumed in Nyambene, Meru, Kenya on the Development Of Colorectal Cancer"*.

We confirm that his research proposal has been defended and approved by the University.

In this regard, we are requesting your office to issue a research license to enable him collect data.

Any assistance accorded to him will be highly appreciated.

Yours sincerely,


Dr. Nancy Rintari (PhD)
Director, Board of Postgraduate Studies

Cc: Dean, School of Health Sciences
CoD, Public Health, Human Nutrition and Dietetics
Postgraduate Coordinator - HND
Supervisors



KENYA METHODIST UNIVERSITY

P. O. BOX 267 MERU - 60200, KENYA
TEL: 254-064-30301/31229/30367/31171

FAX: 254-64-30162
EMAIL: info@kemu.ac.ke

Our Ref: KeMU/ISERC/PHT/06/2025

May 12, 2025

ONDUSO BRIAN MOINDI
PHT-3-0180-1/2024

Dear Brian,

SUBJECT: EFFECT OF CARCINOGENIC HEAVY METALS IN FOOD CROPS GROWN AND CONSUMED IN NYAMBENE, MERU, KENYA ON THE DEVELOPMENT OF COLORECTAL CANCER

This is to inform you that Kenya Methodist University Institutional Scientific Ethics and Review Committee has reviewed and approved your research proposal. Your application approval number is KeMU/ISERC/PHT/06/2025. The approval period is 12th May, 2025 – 12th May, 2026.

This approval is subject to compliance with the following requirements:-

- I. Only approved documents including (informed consents, study instruments, MTA) will be used.
- II. All changes including (amendments, deviations, and violations) are submitted for review and approval by Kenya Methodist University Institutional Scientific Ethics and Review Committee.
- III. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to KeMU ISERC within 72 hours of notification.
- IV. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to KeMU ISERC within 72 hours.

- VI. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
- VII. Submission of an executive summary report within 90 days upon completion of the study to KeMU ISERC.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) <https://oris.nacosti.go.ke> and also obtain other clearances needed.

Yours sincerely,



MR. HERBERT KIBEBE
CHAIR (ISERC)

Appendix 3: NACOSTI permit



REPUBLIC OF KENYA



NATIONAL COMMISSION FOR
SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 787787

RESEARCH LICENSE

Date of Issue: 10/May/2025



This is to Certify that Mr.. Onduso Moindi of Kenya Methodist University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Meru on the topic: EFFECT OF CARCINOGENIC HEAVY METALS IN FOOD CROPS GROWN AND CONSUMED IN NYAMBENE, MERU-KENYA, ON THE DEVELOPMENT OF COLORECTAL CANCER for the period ending : 10/May/2026.

Deputy Director NATIONAL
COMMISSION FOR
SCIENCE, TECHNOLOGY &
INNOVATION

License No: NACOSTI/P/25/4173633

Applicant Identification Number

787787



document,

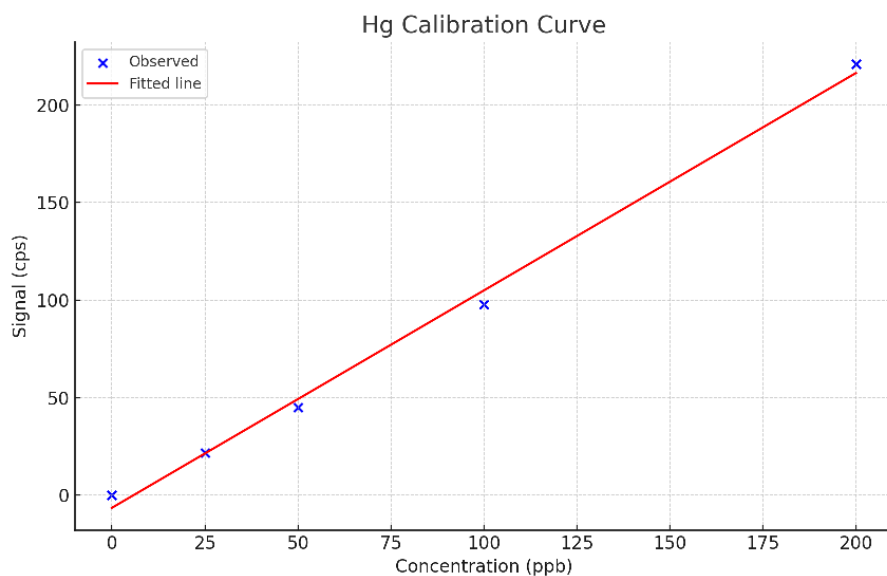
The National Commission for Science, Technology and Innovation, hereafter referred to as the Commission, was the established under the Science, Technology and Innovation Act 2013 (Revised 2014) herein after referred to as the Act. The objective of the Commission shall be to regulate and assure quality in the science, technology and innovation sector and advise the Government in matters related thereto.

CONDITIONS OF THE RESEARCH LICENSE

1. The License is granted subject to provisions of the Constitution of Kenya, the Science, Technology and Innovation Act, and other relevant laws, policies and regulations. Accordingly, the licensee shall adhere to such procedures, standards, code of ethics and guidelines as may be prescribed by regulations made under the Act, or prescribed by provisions of International treaties of which Kenya is a signatory to.
2. The research and its related activities as well as outcomes shall be beneficial to the country and shall not in any way;
 - i. Endanger national security
 - ii. Adversely affect the lives of Kenyans
 - iii. Be in contravention of Kenya's international obligations including Biological Weapons Convention (BWC), Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), Chemical, Biological, Radiological and Nuclear (CBRN).
 - iv. Result in exploitation of intellectual property rights of communities in Kenya
 - v. Adversely affect the environment
 - vi. Adversely affect the rights of communities
 - vii. Endanger public safety and national cohesion
 - viii. Plagiarize someone else's work
3. The License is valid for the proposed research, location and specified period.
4. Neither the license nor any rights thereunder are transferable.
5. The Commission reserves the right to cancel the research at any time during the research period if in the opinion of the Commission the research is not implemented in conformity with the provisions of the Act or any other written law.
6. The Licensee shall inform the relevant County Director of Education, County Commissioner and County Governor before commencement of the research.
7. Excavation, filming, movement, and collection of specimens are subject to further necessary clearance from relevant Government Agencies.
8. The License does not give authority to transfer research materials.
9. The Commission may monitor and evaluate the licensed research project for the purpose of assessing and evaluating compliance with the conditions of the License.
10. The Licensee shall submit one hard copy, and upload a soft copy of their final report (thesis) onto a platform designated by the Commission within one year of completion of the research.
11. The Commission reserves the right to modify the conditions of the License including cancellation without prior notice.
12. Research, findings and information regarding research systems shall be stored or disseminated, utilized or applied in such a manner as may be prescribed by the Commission from time to time.
13. The Licensee shall disclose to the Commission, the relevant Institutional Scientific and Ethical Review Committee, and the relevant national agencies any inventions and discoveries that are of National strategic importance.
14. The Commission shall have powers to acquire from any person the right in, or to, any scientific innovation, invention or patent of strategic importance to the country.
15. Relevant Institutional Scientific and Ethical Review Committee shall monitor and evaluate the research periodically, and make a report of its findings to the Commission for necessary action.

National Commission for Science, Technology and
Innovation(NACOSTI),
Off Waiyaki Way, Upper Kabete,
P. O. Box 30623 - 00100 Nairobi, KENYA
Telephone: 020 4007000, 0713788787,
0735404245
E-mail: dg@nacosti.go.ke
Website: www.nacosti.go.ke

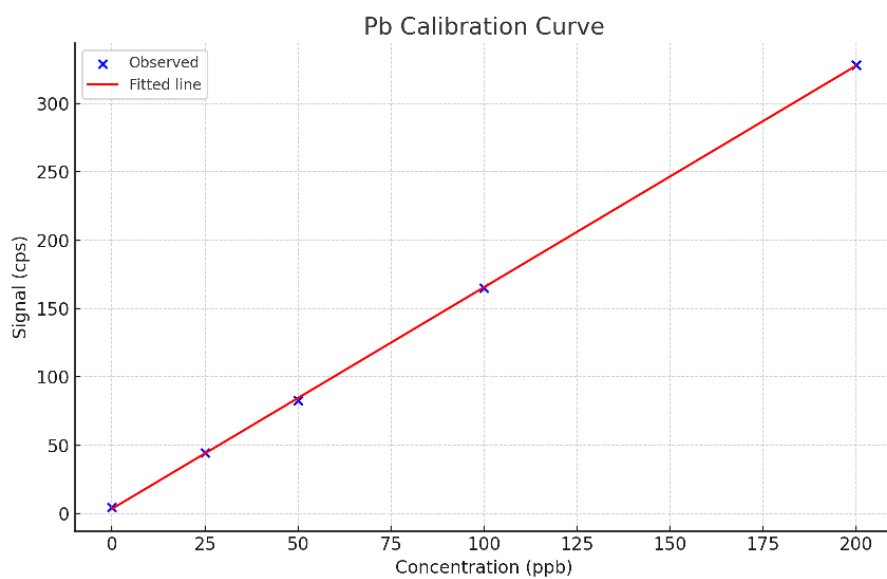
Appendix 4: Hg Calibration curve



Calibration Equation: $y = 1.1141x + -6.4458$

Coefficient of Determination (R^2): 0.9957

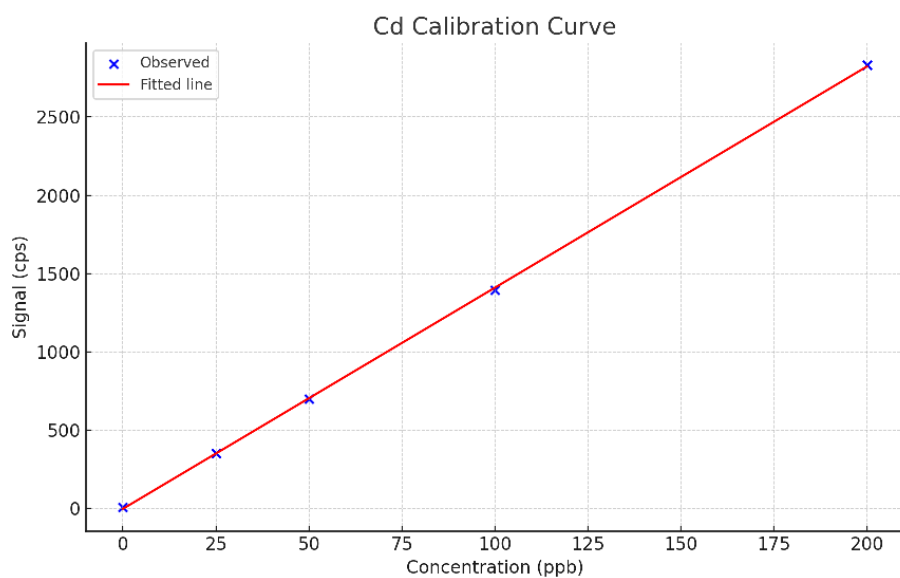
Appendix 5: Pb Calibration curve



Calibration Equation: $y = 1.6212x + 3.4732$

Coefficient of Determination (R^2): 0.9999

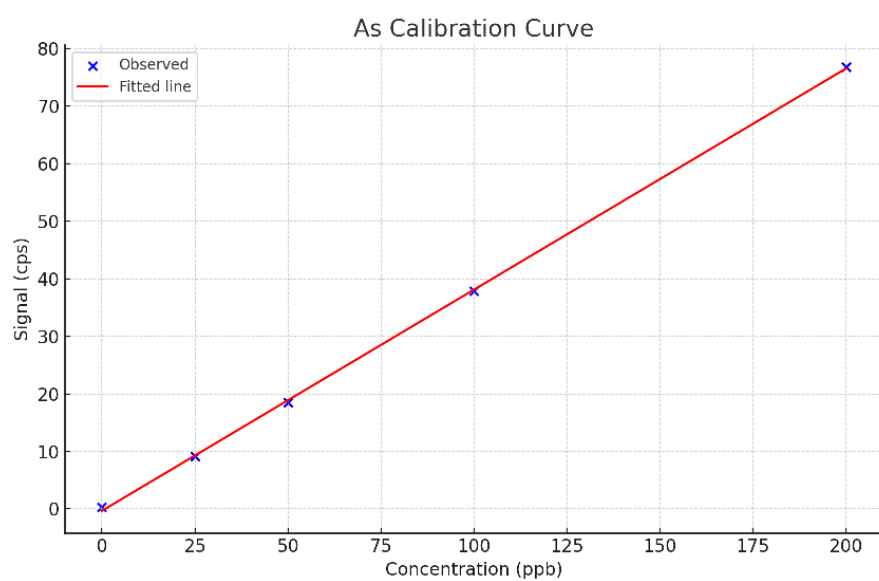
Appendix 6: Cd Calibration curve



Calibration Equation: $y = 14.1396x + -4.6591$

Coefficient of Determination (R^2): 0.9999

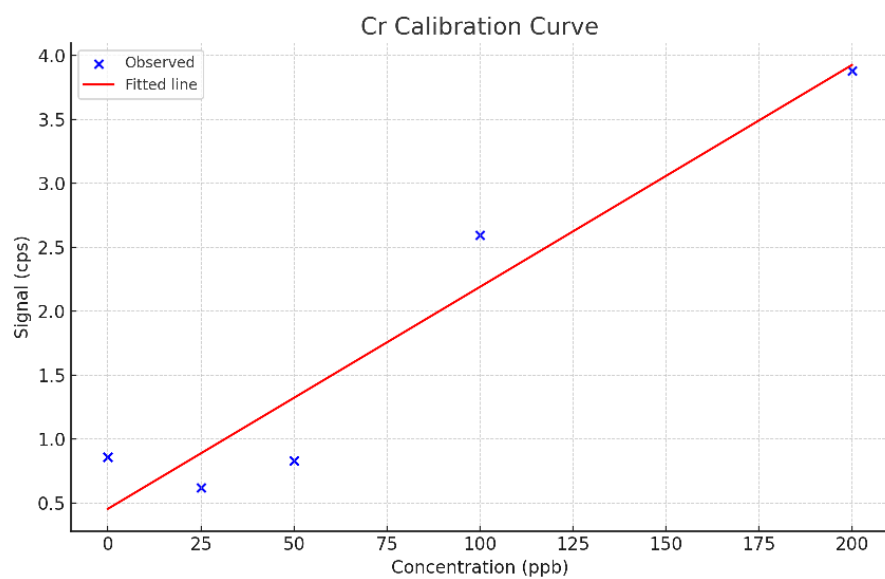
Appendix 7: As Calibration curve



Calibration Equation: $y = 0.3845x + -0.3275$

Coefficient of Determination (R^2): 0.9998

Appendix 8: Cr Calibration curve



Calibration Equation: $y = 0.0174x + 0.4536$

Coefficient of Determination (R^2): 0.9212