

**AKENTEN APPIAH-MENKA UNIVERSITY OF SKILLS TRAINING AND  
ENTREPRENEURIAL DEVELOPMENT**

**HEALTH RISKS ASSOCIATED WITH CONTAMINANTS IN THE LAKE  
BOSOMTWE, GHANA**

**DANIEL KYEI -BAFFOUR QUACOE**

**2025**

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ENTREPRENEURIAL DEVELOPMENT**

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BOSOMTWE, GHANA.**

**BY**

**DANIEL KYEI -BAFFOUR QUACOE**

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**A Thesis Submitted to the School of Graduate Studies, Akenten Appiah-Menka  
University of Skills Training and Entrepreneurial Development, in partial  
fulfillment of the requirements for the award of a Master of Philosophy degree in  
Environmental and Occupational Health Education.**

**JULY, 2025**

## **DECLARATION**

### **Candidate's Declaration**

I hereby declare that this thesis, with the exception of quotation and references contained in published works which have been duly acknowledged; is the result of own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Name: **DANIEL KYEI-BAFFOUR QUACOE**

Signature: ..... Date: .....

### **Supervisors' Declaration**

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the Appiah-Menka University of Skills Training and Entrepreneurial Development.

**Principal Supervisor's Name: DR. DENIS DEKUGMEN YAR**

Signature: ..... Date: .....

**Co-Supervisor's Name: MR. BENJAMIN MAKIMILUA TIIMUB**

Signature: ..... Date: .....

## ABSTRACT

This study assessed the physicochemical, microbial, and heavy metal contamination of water from Lake Bosomtwe and the associated health risks using a cross-sectional design. A total of 100 respondents from surrounding communities participated in a survey on water use and waste management practices, and 50 water samples were collected from multiple locations in the lake using cluster sampling. Physicochemical parameters were analyzed using standard procedures: pH was measured with a Mettler Toledo SevenCompact pH meter, turbidity with a Hach 2100Q turbidimeter, total dissolved solids (TDS) and electrical conductivity (EC) using Hanna HI 8734 and HI 9033 meters, and fluoride, sulphate, nitrate, and free chlorine were determined using a Hach DR 6000 spectrophotometer following SPADNS, turbidimetric, cadmium reduction, and DPD titrimetric methods. Microbial quality for *Escherichia coli*, Total Coliforms, Faecal Coliforms, Salmonella, and Enterococcus was assessed using membrane filtration and selective culture media (APHA, 2017). Heavy metals, including arsenic and mercury, were quantified using atomic absorption spectroscopy (PerkinElmer AAnalyst 800) with graphite furnace digestion and calibration standards. The results showed that physicochemical parameters were within acceptable limits: pH (8.6–8.8), turbidity (0.90–4.50 NTU), TDS (85–420 ppm), fluoride (0.45–0.80 mg/L), sulphate (3.8–60 mg/L), EC (290–1600  $\mu\text{S}/\text{cm}$ ; mean  $\sim 1350$   $\mu\text{S}/\text{cm}$ ), nitrate (22–70 mg/L), and free chlorine (0.00–0.04 mg/L). Microbial loads of *E. coli* ( $\sim 280,000$  CFU/g), Total Coliforms, and Faecal Coliforms exceeded WHO guidelines, which recommend 0 CFU/100 mL for drinking water and  $\leq 1,000$  CFU/100 mL for recreational water. Salmonella was not detected, while Enterococcus was present in high concentrations. Arsenic concentration was elevated at 85  $\mu\text{g}/\text{L}$  and mercury at 0.0006  $\mu\text{g}/\text{L}$ . Hazard quotients (HQ<sub>ing</sub> and HQ<sub>derm</sub>) and the hazard index (HI = 0.42–0.56)

indicated that non-carcinogenic risks were generally within acceptable limits, though chronic exposure could pose health concerns. Regarding waste management, 63% of respondents lacked proper disposal infrastructure, with open dumping (34%) and burning (28%) being common. However, 78% were willing to participate in recycling if facilities were provided, and 81% of law-aware respondents engaged in clean-up efforts. Perception of plastic waste as a serious issue was significantly associated with willingness to recycle (Chi-square = 95.00,  $p < 0.001$ ). The study concludes that Lake Bosomtwe's water quality is compromised, posing health risks from microbial and heavy metal contamination. Mitigation strategies are recommended to safeguard this important ecological and recreational resource.

## ACKNOWLEDGMENT

I would like to express my deepest gratitude to everyone who has supported me throughout my thesis research and writing. This work would not have been possible without their guidance, encouragement, and assistance.

First and foremost, I want to thank my supervisors, Dr. Denis Dekugmen Yar and Mr. Benjamin Makimilua for their invaluable mentorship, insightful feedback, and unwavering support throughout this project. Their expertise and patience have been instrumental in shaping the direction of this thesis and enhancing the quality of my work.

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I would like to give a special thanks to AAMUSTED Mampong lab, Mampong Environmental Health and Sanitation Department, whose resources and collaborative environment provided me with the tools and knowledge necessary to complete this thesis. I am also grateful to my fellow students and colleagues for their intellectual cooperation, stimulating discussions, and friendship. The support of my peers has made this journey easier and more enjoyable. Thank you all for being a part of this accomplishment.

## **DEDICATION**

This thesis is dedicated to my family.

## TABLE OF CONTENT

|  |      |
|--|------|
| DECLARATION.....   | iii  |
| ABSTRACT.....  | iv   |
| ACKNOWLEDGMENT.....  | iv   |
| DEDICATION .....   | vii  |
| TABLE OF CONTENT .....   | viii |
| LIST OF TABLES .....   | xi   |
| CHAPTER ONE .....  | 1    |
| INTRODUCTION .....   | 1    |
| 1.1 Background of the Study .....                                | 1    |
| 1.2 Statement of the problem.....                                | 1    |
| 1.3 Objectives of the Study.....                                 | 3    |
| 1.4 Research questions.....                                      | 4    |
| 1.5 Justification of the Study .....                             | 4    |
| 1.6 Significance of the Study .....                              | 4    |
| 1.7 Scope of the Study .....                                     | 5    |
| 1.6 Purpose of the study.....                                    | 5    |
| 1.7 Delimitations of the Study .....                             | 6    |
| 1.8 Limitations of the Study.....                                | 6    |
| 1.9 Organization of the Study .....                              | 6    |
| CHAPTER TWO .....  | 8    |
| RELATED LITERATURE REVIEW .....                                  | 8    |
| 2.1 Introduction.....  | 8    |
| 2.2 Global Overview of Freshwater Contamination .....            | 8    |
| 2.3 Freshwater Pollution in Africa .....                         | 10   |
| 2.4 Pollution and Water Quality in Ghana .....                   | 12   |
| 2.5 Physicochemical Parameters of Water Quality .....            | 13   |
| 2.6 Microbial quality of Freshwater Bodies .....                 | 17   |
| 2.7 Sources and Impact of Plastic Waste in Water Bodies.....     | 18   |
| 2.8 Challenges in Managing Plastic Waste .....                   | 20   |
| 2.9 Health Risks Associated with Contaminated Water.....         | 22   |
| 2.10 Waterborne Diseases Linked to Contaminated Freshwater ..... | 25   |
| 2.12 Impact of Water Pollution on Aquatic Life.....              | 27   |
| 2.12 Socioeconomic Implications of Water Pollution .....         | 29   |
| 2.13 Strategies for Improving Water Quality.....                 | 32   |
| 2.14 Summary of Literature Review.....                           | 34   |
| CHAPTER THREE .....  | 35   |
| RESEARCH METHODOLOGY.....  | 35   |
| 3.1 Introduction.....  | 35   |
| 3.2 Research Design.....   | 35   |
| 3.3 Study Area.....  | 35   |
| 3.3.1 Overview of Lake Bosomtwe .....                            | 35   |
| 3.4 Study Population and Sampling Techniques.....                | 37   |
| 3.4.1 Target Population and Inclusion Criteria.....              | 37   |
| 3.4.2 Sample Size Determination.....                             | 37   |
| 3.4.3 Sampling Techniques .....                                  | 38   |

|   |    |
|---|----|
| 3.5 Data Collection Tools and Methods.....  | 39 |
| 3.5.1 Structured Questionnaires.....  | 39 |
| 3.6 Water Samples and sampling techniques.....  | 39 |
| 3.7 Laboratory Analysis.....  | 40 |
| 3.7.1 <i>Physicochemical Parameters Analysis</i> .....  | 40 |
| 3.7.2 Quality Control and Assurance.....  | 42 |
| 3.7.3 Heavy Metal Analysis Using Atomic Absorption Spectroscopy (AAS).....                          | 42 |
| Adjustment for Blank Correction.....  | 44 |
| 3.7.4 Microbial quality.....  | 45 |
| 3.8 Data Analysis and Health Risk Assessment.....   | 46 |
| 3.8.1 Statistical Analysis.....   | 46 |
| 3.9 Quality Control and Quality Assurance (QA/QC).....  | 49 |
| 3.10 Ethical Considerations.....  | 50 |
| CHAPTER FOUR.....   | 51 |
| RESULTS AND DISCUSSION.....   | 51 |
| 4.0 Introduction.....   | 51 |
| 4.1 Physicochemical Parameters of Water Samples from Lake Bosomtwe.....                             | 51 |
| of Water Samples.....   | 52 |
| 4.1.1 Key Observations and Interpretation of Physicochemical.....                                   | 53 |
| 4.2 Causes of Persistent Plastic Waste Pollution in Lake Bosomtwe.....                              | 54 |
| 4.2.1 Demographic Characteristics.....  | 54 |
| 4.2.2 Waste Management Practices and Environmental Awareness.....                                   | 54 |
| 4.2.3 Plastic Waste Disposal Methods.....   | 55 |
| 4.2.4 Perception of Plastic Waste as a Serious Problem.....   | 56 |
| 4.2.5 Association Between Awareness of Laws and Clean-up Participation.....                         | 56 |
| 4.2.6 Relationship Between Perceived Seriousness and Recycling Willingness.....                     | 57 |
| 4.3.1 Concentration of Heavy Metals in Water Samples.....   | 58 |
| 4.3.2 Human Health Risk Assessment.....   | 59 |
| 4.3.3 Exposure dose (Ingestion vs Dermal).....  | 60 |
| 4.3.4 Hazard Quotient (Ingestion vs Dermal Contact).....  | 61 |
| 4.3.5 Hazard Quotient (HQ <sub>ing</sub> ) and Cancer Risk (CR) of Metals.....                      | 62 |
| 4.3.6 Chronic Daily Intake (CDI) of Heavy Metals.....   | 63 |
| 4.3.7 Cancer Risk (CR) Associated with Arsenic (As) and Cadmium (Cd).....                           | 64 |
| 4.3.8 Hazard Index (HI) Across the Sampling Locations.....  | 65 |
| 4.4 Microbial contamination level of Lake Bosomtwe compared with the WHO<br>permissible levels..... | 66 |
| 4.4.1 The microbial quality of Lake Bosomtwe.....   | 66 |
| 4.4.2 Microbial Concentrations Across all Samples.....  | 67 |
| 4.4.3 Spatial Distribution of Microbial Contamination.....  | 68 |
| 4.5 Discussion of findings.....   | 69 |
| 4.5.1 Physicochemical Parameters of Water Samples from Lake Bosomtwe.....                           | 69 |
| 4.5.2 Key Observations of Physicochemical Parameters.....   | 70 |
| 4.5.3 Demographic Characteristics of Respondents.....   | 71 |
| 4.5.4 Waste Management Practices and Environmental Awareness.....                                   | 72 |
| 4.5.5 Plastic Waste Disposal Methods.....   | 72 |
| 4.5.6 Perception of Plastic Waste as a Serious Problem.....   | 73 |

|   |     |
|---|-----|
| 4.5.7 Association Between Awareness of Laws and Clean-up Participation .....    | 73  |
| 4.5.8 Relationship Between Perceived Seriousness and Recycling Willingness..... | 73  |
| 4.5.9 Concentration of Heavy Metals in Water Samples .....                      | 74  |
| 4.5.10 Human Health Risk Assessment .....                                       | 75  |
| 4.5.11 Exposure Dose (Ingestion vs Dermal) .....                                | 75  |
| 4.5.12 Hazard Quotient (Ingestion vs Dermal Contact) .....                      | 76  |
| 4.5.13 Chronic Daily Intake (CDI) of Heavy Metals.....                          | 76  |
| 4.5.14 Cancer Risk (CR) Associated with Arsenic (As) and Cadmium (Cd) .....     | 77  |
| 4.5.15 Hazard Index (HI) Across the Sampling Locations .....                    | 78  |
| 4.5.16 Microbial Quality of Lake Bosomtwe .....                                 | 78  |
| 4.5.17 Microbial Concentrations Across All Samples .....                        | 78  |
| 4.5.18 Spatial Distribution of Microbial Contamination .....                    | 79  |
| CHAPTER FIVE .....  | 80  |
| SUMMARY OF FINDINGS, CONCLUSION, AND RECOMMENDATIONS .....                      | 80  |
| 5.1 Summary of Findings .....   | 80  |
| 5.2 Conclusion.....   | 82  |
| 5.3 Recommendations .....   | 83  |
| APPENDICES.....   | 122 |

## LIST OF TABLES

|   |    |
|---|----|
| Table 3.1: Sample Frame for Lake Workers and Residents.....                   | 38 |
| Table 4.1: Physicochemical and Chemical Parameters .....                      | 52 |
| Table 4.2: Demographic Characteristics of Respondents .....                   | 54 |
| Table 4.3: Waste Management and Awareness .....                               | 55 |
| Table 4.4: Awareness of Laws and Clean-up Participation .....                 | 57 |
| Table 4.5: Perception of Seriousness and Recycling Willingness .....          | 57 |
| Table 4.7 Human Health Risk Assessment .....                                  | 60 |
| Table 4.8 Microbial quality level compared with the WHO permissible levels... | 66 |
| Table 4.9 Microbial Contaminants in Lake Bosomtwe .....                       | 67 |

## LIST OF FIGURES

|  |    |
|--|----|
| Figure 3.1 Map of Lake Bosomtwe .....  | 31 |
| Figure 4.1 Water Parameters with WHO Guideline.....                            | 44 |
| Figure 4.2: Plastic Waste Disposal Methods.....                                | 46 |
| Figure 4.3: Perception of Plastic Waste as a Serious Problem .....             | 47 |
| Figure 4.4 Exposure dose (Ingestion vs Dermal).....                            | 52 |
| Figure 4.5 Hazard Quotient (Ingestion vs Dermal Contact).....                  | 53 |
| Figure 4.6 Hazard Quotient (HQ_ing) and Cancer Risk (CR) of Metals.....        | 54 |
| Figure 4.7 Chronic Daily Intake (CDI) of Heavy Metals .....                    | 55 |
| Figure 4.8 Cancer Risk (CR) Associated with Arsenic (As) and Cadmium (Cd)..... | 56 |
| Figure 4.9 Hazard Index (HI) Across the Sampling Locations.....                | 57 |
| Figure 4.8 Microbial Concentrations Across all Samples.....                    | 60 |
| Figure 4.9 Spatial Distribution of Microbial Contamination.....                | 61 |



Our Ref: CHREP/AP/188/21

20th June, 2025

Mr. Daniel Kyei -Baffour Quacoe  
Akenten Appiah-Menka University of Skills Training  
and Entrepreneurial Development,  
Department of Public Education.  
KUMASI-GHANA.

Dear Madam,

**LETTER OF APPROVAL**

**Protocol Title:** " Health Risks Associated with Contaminants in the Lake Bosomtwe, Ghana"  
**Proposed Site:** Bosomtwe District.  
**Sponsor:** Self-Sponsored.  
**Student:** Mr. Daniel Kyei-Baffour Quacoe  
**Supervisor:** Dr. Joana Apenkwa

Your submission to the Committee on Human Research, Publications, and Ethics on the above-named protocol refer. The Committee reviewed the following documents:

- A notification letter of 14th May, 2025 from the Authorities of Lake Bosomtwe, indicating approval for the conduct of the study in the municipality.
- A Completed CHREP Application Form.
- Participant Information Leaflet and Consent Form.
- Research Protocol.
- Questionnaire.


The Committee has considered the ethical merit of your submission and approved the protocol. The approval is for one year, renewable after that, from **20th June, 2025 to 20th June, 2026**. The Committee may, however, suspend or withdraw ethical approval at any time if your study is found to contravene the approved protocol.

Data gathered for the study should be used for the approved purposes only. Permission should be sought from the Committee if any amendment to the protocol or use, other than submitted, is made of your research data.

The Committee should be notified of the actual start date of the project and would expect a report on your study, annually or at the close of the project, whichever one comes first. It should also be informed of any publication arising from the study.

Thank you for your application.

Yours faithfully,



Rev. Prof. John Appiah-Poku,  
Honorary Secretary  
FOR: CHAIRMAN

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background of the Study

Freshwater ecosystems such as lakes, rivers, and ponds are vital for maintaining ecological balance and supporting human development. They provide water for drinking, agriculture, fisheries, and recreation (Mishra, 2023; Daneshi et al., 2023). However, increasing contamination of these water bodies has become a global concern due to its adverse impacts on aquatic life, human health, and sustainable development (Prata et al., 2021; Sarker et al., 2021). Common pollutants such as heavy metals, pathogenic microorganisms, and solid waste enter freshwater bodies through industrial discharge, agricultural runoff, and improper waste disposal (Haque, 2022). Globally, studies have reported rising levels of both chemical and microbial contaminants in surface waters. For instance, Wang et al. (2022) found elevated concentrations of toxic metals in freshwater bodies in China, while Earn et al. (2021) recorded high bacterial loads in rivers across Europe and Asia. These pollutants have been associated with health effects such as neurological disorders, cancers, and gastrointestinal infections (Zhang et al., 2022; Chen and Dong, 2022).

In Africa, rapid urbanization, weak environmental regulations, and poor sanitation have worsened the problem (Adeniran et al., 2022). Studies in Nigeria and Ghana have revealed excessive levels of heavy metals and pathogens in rivers and lakes used for domestic and agricultural purposes (Darko et al., 2022; Kazapoe et al., 2023). In Ghana, water bodies such as the Pra, Offin, and Volta Rivers have been polluted by illegal mining, farming activities, and domestic waste disposal (Onsrud, 2023; Oloruntoba et al., 2024). Lake Bosomtwe, Ghana's only natural lake and a UNESCO Biosphere Reserve, provides water for drinking, agriculture, and fishing to more than 20,000

residents (Amu-Mensah, 2020; Gebremedhin and Belliethathan, 2020). However, its water quality has declined due to anthropogenic activities such as waste dumping and poor sanitation around the lake (Oduro, 2023). Okyere (2020) reported mercury and lead concentrations in fish exceeding WHO limits, while bacterial contamination by *Escherichia coli* and *Vibrio* species was also detected (Gwenzi et al., 2023).

Additionally, poor plastic waste management within the lake's catchment area has contributed to environmental degradation and the potential leaching of toxic substances (Boateng et al., 2024). Plastic accumulation obstructs natural drainage and indirectly worsens water quality. The deterioration of Lake Bosomtwe's water quality has significant implications for public health, fisheries, tourism, and local livelihoods (Amoako et al., 2023). Furthermore, continuous pollution threatens the ecological integrity of the lake and its recognition as a UNESCO Biosphere Reserve (Takyi et al., 2021). Despite these challenges, few studies have integrated assessments of physicochemical parameters, microbial quality, and human health risks from heavy metals, alongside plastic waste management around the lake. This study, therefore, sought to fill this gap by assessing the water quality of Lake Bosomtwe and its associated health risks.

## **1.2 Statement of the problem**

Lake Bosomtwe, Ghana's only natural lake and a UNESCO Biosphere Reserve, is increasingly threatened by pollution from agricultural runoff, domestic waste, and human activities within its catchment area. This pollution has led to declining water quality, posing risks to human health, aquatic life, and the livelihoods of over 20,000 people who depend on the lake for drinking water, fishing, irrigation, and tourism (Jambeck et al., 2023; Gani et al., 2024). Studies have reported elevated levels of

contaminants in the lake, including heavy metals, nitrates, and phosphates, which can accumulate in aquatic organisms and enter the human food chain (Amoako et al., 2023; Wang et al., 2020). Toxic metals such as mercury, lead, and arsenic have been linked to neurological disorders, kidney damage, and other chronic diseases (Gore et al., 2024; Manyepa et al., 2024). Bacterial contamination, particularly from *Escherichia coli* and *Vibrio* species, has also rendered the water unsafe for domestic use in some communities (Mensah, 2022).

In addition to human health concerns, declining water quality threatens the ecological balance of the lake. The accumulation of pollutants has been associated with loss of biodiversity and reduced fish stocks, affecting the local economy (Bharani et al., 2024). Despite these challenges, few studies have conducted a comprehensive assessment of the physicochemical parameters, microbial quality, and heavy metal contamination of Lake Bosomtwe. The management of plastic waste around the lake is also inadequate, further contributing to pollution. This study aims to fill these gaps by evaluating the water quality of Lake Bosomtwe, assessing microbial and heavy metal contamination, and examining the management of plastic waste accumulation in the lake.

### **1.3 Objectives of the Study**

This study assessed the water quality and its associated health risks from the Lake Bosomtwe. Specifically, it sought to;

1. Evaluate the physicochemical parameters of water from the lake.
2. Assess microbial quality of the lake water.
3. Determine the potential human health risks associated with exposure to heavy metals in Lake Bosomtwe.
4. Investigate the management of plastic waste accumulation around the lake.

#### **1.4 Research questions**

1. What are the levels of the physicochemical parameters of the water from Lake Bosomtwe?
2. What is the microbial quality and loads in the water from the lake?
3. What are the potential human health risks associated with exposure to heavy metals in Lake Bosomtwe?
4. How is plastic waste managed around Lake Bosomtwe?

#### **1.5 Justification of the Study**

Research on freshwater pollution in Africa, particularly in Ghana, is limited despite increasing concerns over plastic waste and water contamination (Awewomom et al., 2024; Oceng et al., 2023). Lake Bosomtwe, Ghana's only natural lake, is vital for livelihoods, biodiversity, and public health, yet it faces growing threats from heavy metal contaminant, microbial contaminants, and poor waste management (Dris et al., 2020; Adeghe et al., 2024). While marine systems have received extensive attention, freshwater bodies like Lake Bosomtwe remain understudied. This study provides baseline data on the lake's physicochemical and microbial status, identifies pollution sources, and assesses health risks associated with contaminated water. The findings will support evidence-based interventions to protect water quality, guide local policies, and raise public awareness. Moreover, safeguarding the lake will help preserve its ecological balance and sustain the fishing and tourism-dependent livelihoods of nearby communities (Mensah, 2022; Takyi et al., 2021).

#### **1.6 Significance of the Study**

This study is significant for environmental conservation, public health, and policy development. By assessing the physicochemical and microbial status of Lake

Bosomtwe, it provides crucial data for understanding pollution trends and health risks. The findings will inform local authorities, environmental agencies, and health professionals in developing targeted interventions to protect water quality. Moreover, the study contributes to the limited body of research on freshwater pollution in Ghana, helping to fill existing knowledge gaps. It also supports sustainable resource management by highlighting the need for improved waste disposal, especially regarding plastic waste. Ultimately, the study will benefit local communities by promoting safer water use, enhancing food safety, and supporting the economic sustainability of fishing and tourism in the Lake Bosomtwe area.

### **1.7 Scope of the Study**

This study investigates the water quality in the Lake Bosomtwe, Ghana, focusing on selected physicochemical parameters, microbial quality, and plastic waste accumulation. It assesses the presence of contaminants and microplastics, along with associated health risks. The research is geographically confined to key sampling sites around the lake and does not address seasonal variations or extend to other water bodies in Ghana. The findings aim to inform local environmental management and policy decisions.

### **1.6 Purpose of the study**

This study aimed to assess health risks linked to contaminants in Lake Bosomtwe, Ghana, focusing on physicochemical parameters, microbial quality, and microplastics in water and local fish species. It also explored the reasons behind plastic waste mismanagement and evaluated the health impacts on local communities, particularly those consuming fish and water from the lake. By generating key data, the study seeks to inform policy, improve environmental management, and promote public health. It was to raise awareness about the importance of protecting freshwater ecosystems and

encourage community involvement in sustainable lake management. In addition, the findings will provide valuable comparisons with other recreational ponds, contributing to broader efforts to manage water bodies in Ghana and beyond.

### **1.7 Delimitations of the Study**

This study focuses on Lake Bosomtwe, Ghana's only natural lake, assessing its contamination by plastic waste, microplastics, and microbial pollutants. The research is limited to examining the water quality within the lake, with particular attention to local communities who rely on the lake's resources. The study excludes other bodies of water in the region and does not explore broader ecological impacts beyond human health risks.

### **1.8 Limitations of the Study**

The study had limitations such as restricted access to remote areas of Lake Bosomtwe, which could impact the comprehensiveness of data collection. Resource constraints also limit the ability to analyze every potential contaminant. In addition, the study's scope does not capture seasonal variations in water quality or pollutant levels, and findings may not be directly applicable to other freshwater bodies in Ghana due to different environmental and local conditions.

### **1.9 Organization of the Study**

The study was organized into five chapters: Chapter One introduces the research background, problem statement, objectives, research questions, justification, significance, scope, purpose, delimitation and limitations of the study. Chapter Two presents a literature review, summarizing relevant research on freshwater contamination and associated health risks. Chapter Three outlines the methodology, including the research design, data collection methods, sampling techniques, and data

analysis procedures. Chapter Four presents the results and discussion, highlighting the findings from water quality analysis, contamination, and associated health risks. Chapter Five concludes the study by summarizing the findings, providing policy recommendations, and suggesting areas for future research.

## CHAPTER TWO

### RELATED LITERATURE REVIEW

#### 2.1 Introduction

This chapter reviews relevant literature on global, African, and Ghanaian freshwater contamination. It examines key issues such as physicochemical water quality, microbial pollution, plastic waste, and associated health risks. The discussion also highlights challenges in managing pollution and explores strategies for improving water quality, providing a foundation for assessing the current state of Lake Bosomtwe.

#### 2.2 Global Overview of Freshwater Contamination

Freshwater contamination is an escalating global concern affecting ecosystems, human health, and water security (Mishra, 2023). Rapid industrialization, urbanization, and agricultural intensification have led to increasing pollution levels in rivers, lakes, and reservoirs (Sarker et al., 2021). The World Health Organization (2020) reports that nearly 80 % of the world's wastewater is released into freshwater systems without adequate treatment. Contaminants such as heavy metals, microplastics, harmful bacteria, and excessive nutrients are responsible for waterborne diseases and ecological disturbances (Bharani et al., 2024). According to Alobid (2022), worsening contamination is limiting access to clean water, affecting both domestic use and agriculture. In response, governments and researchers are advancing policy, technology, and sustainable practices to safeguard freshwater resources. Industrial waste is a major source of contamination, introducing toxic substances such as heavy metals and synthetic chemicals into water bodies. Naqash et al. (2020) found significant levels of microplastics and heavy metals like lead and mercury in European freshwater systems. Münzel et al. (2023) reported high mercury and cadmium concentrations in Germany's Rhine River, linked to neurological and developmental health risks. In China, Xiao et

al. (2020) discovered arsenic and mercury pollution near industrial zones, associated with respiratory illnesses and cancer. Regulations such as the European Union's Water Framework Directive and the US Clean Water Act have helped reduce industrial pollution (Piwowarska et al., 2024). However, emerging contaminants like pharmaceutical residues and endocrine disruptors remain problematic due to limitations in traditional treatment facilities (Botturi et al. 2021).

Agriculture also contributes significantly to freshwater pollution. Excessive use of fertilizers and pesticides leads to nutrient loading, causing eutrophication, algal blooms, and oxygen depletion (Kumar et al., 2021). Bailey et al. (2020) linked nitrogen and phosphorus runoff in the Mississippi River Basin to dead zones in the Gulf of Mexico. Similarly, Chen et al. (2020) associated nutrient pollution in China's Yangtze River with declining oxygen levels and aquatic stress. Agricultural runoff also contaminates drinking water supplies, endangering public health. Ondrasek and Zhang (2023) note that overuse of fertilizers degrades soil quality and reduces productivity. In response, practices such as buffer strips, cover crops, and precision fertilization have been adopted. Luo et al. (2023) showed that integrated nutrient management in China reduced nitrogen runoff and improved yields.

The US Conservation Reserve Program has also promoted more sustainable farming methods. In developing countries, microbial contamination is a major issue due to poor sanitation infrastructure. Afolayan (2021) found widespread *E. coli* contamination in Nigerian rivers. In India, Altalhi and Alrooqi (2024) reported that over 60 % of surface water samples contained harmful bacteria linked to cholera and typhoid outbreaks. Gwenzi et al. (2024) highlighted the impact of weak wastewater treatment systems in sub-Saharan Africa on persistent contamination. To mitigate risks, low-cost

interventions such as ceramic water filters and expanded sewage treatment have been implemented. Huang et al. (2020) found that ceramic filters reduced bacterial loads in rural Bangladesh. Ololade et al. (2024) observed improved water quality in South Africa following upgrades to sewage infrastructure. Nevertheless, Zapana-Churata (2021) emphasized that access to clean water remains difficult in many fast-growing urban areas.

Plastic pollution, particularly microplastics, is another emerging threat to freshwater ecosystems. Belioka and Achilias (2024) estimate that millions of tons of plastic enter water bodies annually, breaking into persistent microplastic particles. McGoran (2023) found high concentrations of microplastics in North America's Great Lakes, raising concerns for aquatic and human health. Chantima et al. (2023) reported similar contamination levels in the Mekong River, driven by poor plastic waste management.

### **2.3 Freshwater Pollution in Africa**

Freshwater pollution is a growing challenge across Africa, driven by rapid urbanization, poor waste management, agricultural runoff, and industrial activities (Zahoor & Mushtaq, 2023). Rivers, lakes, and groundwater sources are increasingly contaminated, posing threats to human health and aquatic ecosystems (Madhav et al., 2020). In Nigeria, studies have reported high levels of coliform bacteria in rivers like Ogun and Osun due to poor sanitation and waste disposal (Ololade et al., 2024; Hasselberg, 2022). Excessive fertilizer use in northern Nigeria has caused nitrate contamination in drinking water, linked to cases of methemoglobinemia among infants (Musa, 2022). Rural groundwater sources have also shown elevated levels of lead, arsenic, and cadmium, primarily from mining and industrial waste (Rosdi, 2022).

In East Africa, Lake Victoria has emerged as a pollution hotspot. Research reveals heavy metal contamination, particularly lead and mercury, from industrial discharge (Chisomo, 2021). Agricultural runoff has led to nitrogen and phosphorus buildup, causing algal blooms and fish deaths (Kimambo, 2021). Microplastics have also increased, with over 1,200 particles per cubic meter recorded (Kurniawan et al., 2024). Despite regional policies like plastic bags and waste management initiatives, enforcement remains weak (Nduwimana et al., 2025). South Africa faces similar issues. The Vaal River is polluted by untreated sewage, industrial effluents, and plastics, with some of the continent's highest microplastic concentrations (Mvovo, 2021). Acid mine drainage has further degraded water quality by introducing toxic metals (Lourenco & Curtis, 2021). Pharmaceuticals and endocrine-disrupting chemicals have also been detected in drinking water (Wee et al., 2022). Though wastewater treatment upgrades and regulations are in place, enforcement challenges persist due to financial constraints (Mpshane-Nkosi, 2024).

West Africa, especially Ghana, is affected by pollution from illegal small-scale gold mining. Rivers like the Pra and Ankobra contain high levels of mercury, cyanide, and arsenic (Amengor, 2024; Jonathan et al., 2023). Similar contamination from artisanal mining has been reported in Burkina Faso (Abdelaal et al., 2023). Government efforts to ban illegal mining and promote safer practices have faced enforcement difficulties. International organizations such as the UNDP are supporting interventions through education and water purification projects (Haile et al., 2024).

In North Africa, water pollution is worsened by the region's water scarcity. The Nile River in Egypt shows contamination from pesticides, heavy metals, and untreated industrial waste (Khalil et al., 2023). In Tunisia, excessive fertilizer use and

pharmaceutical waste have degraded freshwater sources (Galgani et al., 2020; Mbanjwa, 2022). Countries like Egypt and Morocco are expanding wastewater treatment and desalination infrastructure to improve water quality (Ahmed, 2024; Migliore, 2024). Despite ongoing efforts, challenges remain. Financial constraints, weak institutional capacity, and inconsistent enforcement hinder progress (Gyamera et al., 2023). Continental initiatives like the African Water Vision 2025 promote sustainable water management and pollution control, but greater international collaboration, innovation, and local engagement are needed to safeguard Africa's freshwater resources (Aamer, 2023; Nandineni & Dash, 2022).

#### **2.4 Pollution and Water Quality in Ghana**

Freshwater pollution in Ghana has emerged as a significant environmental and public health concern, affecting vital water bodies such as the Volta River, Weija Dam, and Lake Bosomtwe (Alhassan, 2023). Rapid urbanization, industrial growth, agricultural runoff, and poor waste management have all contributed to the decline in water quality (Annan et al., 2022). These water sources increasingly contain heavy metals, microbial pathogens, and excess nutrients, posing risks to aquatic ecosystems and human populations alike (Amuah, 2022; Hasselberg, 2022). The Volta River Basin, critical for irrigation, hydropower, and domestic use, faces contamination from industrial and mining activities. Studies report elevated levels of lead, arsenic, and mercury—often surpassing WHO safety guidelines—particularly due to illegal small-scale mining (galamsey), which poses long-term health risks such as neurotoxicity and kidney damage (Anoyege & Alatinga, 2025; Owusu et al., 2024). Similar concerns exist for the Weija Dam, a key water source for Accra, where faecal contamination and organic pollutants from untreated sewage have been linked to outbreaks of waterborne diseases like cholera and typhoid (Ntajal, 2022; Aminu & Udeze, 2023).

Lake Bosomtwe, Ghana's only natural inland lake, is also under threat from nutrient runoff, deforestation, and domestic waste disposal. These activities have caused increased turbidity and harmful algal blooms (Chakraborty & Chakraborty, 2021). Recent studies have also flagged microplastics as an emerging threat to biodiversity and food safety in the lake (Tella et al., 2025). Galamsey continues to be one of the major drivers of freshwater pollution, particularly in the Pra, Ankobra, and Offin Rivers. Mercury levels in these rivers have been recorded at 10–20 times above international safety thresholds, with contaminated sediments affecting aquatic life and communities relying on these waters (Takyi et al., 2021; Hossain et al., 2024). Long-term exposure may lead to chronic health issues such as cancer and reproductive disorders (Amuah et al., 2022). In response, the Ghana Water Resources Commission has strengthened its regulatory framework through policies like the National Water Policy (2021), which emphasizes pollution control and sustainable water management (Katusiime & Schütt, 2020). Government-led operations, such as “Operation Vanguard,” have aimed to curb illegal mining (Ayima, 2024), though enforcement remains hindered by limited resources and political challenges (Kazapoe et al., 2023). Community-based initiatives and support from organizations like the UNDP and World Bank have also promoted better sanitation, eco-friendly farming, and alternative livelihoods to reduce reliance on illegal mining (Mulaba-Bafubiandi et al., 2023).

## **2.5 Physicochemical Parameters of Water Quality**

The assessment of physicochemical parameters is crucial for understanding water quality and identifying potential sources of contamination (Zhang et al., 2022). These parameters, which include temperature, pH, turbidity, dissolved oxygen (DO), total dissolved solids (TDS), electrical conductivity (EC), nitrates, phosphates, and heavy metals, serve as key indicators of pollution. Monitoring these factors is vital not only

for safeguarding aquatic ecosystems but also for ensuring the health and safety of populations dependent on freshwater resources (Tordzro, 2022). In Ghana, rising water temperatures have been linked to human activities such as industrial discharge, deforestation, and climate change, all contributing to elevated water temperatures in several water bodies, including the Volta, Densu, and Odaw rivers. Elevated temperatures reduce oxygen solubility and impair the metabolic functions of aquatic organisms. Tay (2023) observed temperature increases of up to 4°C in sections of the Volta River, which significantly reduced oxygen levels and stressed aquatic life. Similarly, Eduful et al. (2022) documented temperature spikes in urban rivers, where industrial waste discharge and reduced riverbank vegetation were major contributors. These temperature changes have serious implications for the health of aquatic ecosystems, as they disrupt biological processes, such as the survival of fish and other organisms.

Water pH is another critical factor that reflects water quality. Deviations from the neutral range (6.5–8.5) often point to contamination from industrial effluents, mining activities, or agricultural runoff. In mining-affected regions like the Pra and Ankobra Rivers, Fiati (2020) recorded pH levels as low as 4.5, indicating acid mine drainage (AMD). AMD leads to the release of toxic heavy metals into water bodies, which can harm aquatic organisms and pose serious health risks to communities relying on these water sources. In contrast, some urban rivers show pH levels above 9.0, often caused by untreated industrial discharges, which can lead to skin irritation and gastrointestinal issues for humans (Masime, 2022). Turbidity, a measure of water clarity, is influenced by suspended particles, including sediments, organic matter, and pollutants. High turbidity reduces light penetration, impeding photosynthesis in aquatic plants and providing a medium for harmful microorganisms. In the Volta River, Chuku et al. (2022)

found turbidity levels reaching 80 NTU, four times higher than the WHO-acceptable limit of 20 NTU. This was attributed to soil erosion, deforestation, and illegal small-scale mining (galamsey). Similarly, Tenebe et al. (2022) reported increased turbidity in urban rivers, creating an environment conducive to bacteria like *Escherichia coli*, raising concerns over waterborne diseases such as cholera and typhoid.

Dissolved oxygen (DO) is a crucial indicator of water quality, directly influencing the survival of aquatic organisms. Reduced DO levels are often a result of organic pollution from untreated sewage or agricultural runoff, which creates hypoxic conditions harmful to fish populations. Amu-Mensah (2020) found DO levels as low as 2 mg/L in the Densu and Odaw rivers, well below the optimal range of 6–8 mg/L for healthy aquatic ecosystems. Similarly, Adino (2024) reported seasonal oxygen depletion in Lake Bosomtwe, leading to fish mortality events, severely affecting the fishing industry. The decline in DO levels is primarily linked to increased organic waste from human settlements and agricultural activities, which underscores the urgent need for improved waste management practices (David Jr et al., 2022). Total dissolved solids (TDS) and electrical conductivity (EC) are important parameters that reflect the concentration of dissolved salts and minerals in water. Elevated TDS levels can affect both the taste and safety of drinking water, with long-term exposure potentially leading to kidney-related health problems. Meena et al. (2022) observed TDS concentrations exceeding 1,500 mg/L in parts of the Weija Dam, which is significantly above the WHO threshold of 1,000 mg/L. This high concentration of dissolved solids is attributed to industrial discharge and untreated wastewater. Similarly, increased EC levels, often associated with agricultural runoff and excessive fertilizer use, have been recorded in various water bodies across Ghana, highlighting the negative impact of unsustainable farming practices on water resources (Aryee et al., 2022). Nutrient pollution, particularly from

nitrates and phosphates, has contributed to the eutrophication of several freshwater bodies in Ghana. Excessive nutrient enrichment can trigger harmful algal blooms that deplete oxygen levels and disrupt aquatic ecosystems. Chitja et al. (2024) reported nitrate concentrations exceeding 50 mg/L in farming areas, which is double the WHO safety limit. High nitrate levels pose serious health risks, particularly for infants, as they are associated with methemoglobinemia, also known as "blue baby syndrome." Eli (2023) also observed recurring algal blooms in the Barekese Reservoir, a key drinking water source for Kumasi. These blooms not only degrade water quality but also increase the cost of water treatment, making it more expensive for local authorities and consumers.

Heavy metal contamination is one of the most serious threats to water quality in Ghana, particularly in mining-intensive regions. Studies by Cudjoe et al. (2011) and Saim (2021) found alarming levels of mercury, lead, and arsenic in rivers near mining operations. For example, mercury concentrations in the Tano River were recorded at 0.05 mg/L, five times higher than the WHO-recommended limit. Prolonged exposure to these heavy metals has been linked to severe health issues, including neurological disorders, kidney damage, and developmental problems in children (Myers et al., 2023). Furthermore, the bioaccumulation of these metals in fish poses additional risks to consumers, particularly those who rely on fish as a primary source of protein. Addressing these water quality challenges requires a multi-faceted approach that includes stronger regulatory frameworks, community engagement, and the adoption of technological interventions. Community-led water monitoring programs, where local residents are trained to detect and report pollution incidents, have been emphasized as a key strategy to enhance water quality management (Myers et al., 2023).

## 2.6 Microbial quality of Freshwater Bodies

Microbial contamination of freshwater bodies in Ghana remains a serious public health issue, particularly in areas where these water sources are used for drinking, cooking, and other household needs (Yeboah *et al.*, 2022). Harmful bacteria like *Escherichia coli*, *Salmonella*, and *Vibrio cholerae* are commonly found in these waters, mainly due to poor waste management, untreated sewage discharge, and agricultural runoff (Tariq & Mushtaq, 2023). The presence of these bacteria is a clear sign of faecal pollution, posing a major risk of waterborne diseases, especially in communities with inadequate sanitation systems. A study by Ahiabor and Donkor (2025) revealed that nearly 96% of sachet water samples tested in Ghana contained bacterial contamination, with about 76% of the 2,276 samples analyzed showing clear signs of microbial presence. This highlights how widespread the issue is, affecting not just natural water sources but even supposedly treated water meant for consumption. Similarly, research by Tettey *et al.* (2020) found *Salmonella* and *Shigella* in the Barekese Reservoir, a major water supply for Kumasi, raising concerns about the safety of drinking water in urban areas.

The health implications of contaminated water are alarming. Waterborne diseases, such as diarrhoea, typhoid, and dysentery, are leading causes of illness in Ghana, especially among children under five (Salifu, 2020). A national survey by Jonathan *et al.* (2023) linked high bacterial levels in drinking water to frequent cases of typhoid fever and other gastrointestinal infections. Several measures have been introduced to address microbial contamination, with varying levels of success. The Ghana Water Company Limited (GWCL) has implemented chlorine disinfection and filtration techniques in major cities, which have helped reduce bacterial loads in treated water (Ohene-Kwayisi, 2023). However, rural communities still struggle with access to clean water, as many depend on untreated rivers and streams. A recent study at the University of

Environment and Sustainable Development (UESD) showed that microbial contamination levels in some water supply systems exceeded safe limits, emphasizing the need for regular water quality monitoring and maintenance (Griffin *et al.*, 2024). Tackling this issue requires a multi-faceted approach. Strengthening environmental policies, investing in modern wastewater treatment plants, and raising awareness about proper sanitation practices are all critical steps (Geldreich, 2020). More importantly, local communities need to be involved in water quality monitoring and protection efforts to ensure long-term solutions. Collaboration among government agencies, non-governmental organizations, and international partners is essential to improving water quality and reducing the health risks associated with microbial contamination in Ghana (Kessey & Nyarko, 2021).

## **2.7 Sources and Impact of Plastic Waste in Water Bodies**

Plastic pollution in freshwater ecosystems has become an alarming environmental challenge, with waste accumulating in lakes, rivers, and reservoirs at an unprecedented rate (Cudjoe *et al.*, 2023). The problem is largely driven by poor waste disposal practices, urban runoff, industrial discharges, and fishing activities (Kessey & Nyarko, 2021). In Ghana, plastic waste is a major contributor to water pollution, affecting significant water bodies such as Lake Bosomtwe and the Volta River. A study by Yakubu *et al.* (2020) found that over 80% of sampled freshwater sources in Ghana contained plastic particles, with polyethene and polypropylene being the most frequently detected. This widespread contamination threatens aquatic life, ecosystem health, and human well-being. One of the most concerning aspects of plastic pollution is the presence of microplastics, tiny plastic fragments that result from the breakdown of larger plastic debris. These microplastics absorb toxic pollutants and persist in aquatic environments for years (Bhatt *et al.*, 2021).

Jonathan *et al.* (2023) found significant microplastic contamination in the sediments and surface water concentrations reaching as high as 7,500 particles per cubic meter. This raises concerns about bioaccumulation, as fish and other aquatic organisms ingest these particles. A related study by Salifu (2020) examined fish from the Pra River and found plastic fibres in the digestive tracts of multiple species, suggesting that microplastics have entered the food chain, potentially affecting human health. Beyond harming aquatic life, plastic waste also degrades water quality. As plastics break down, they release harmful chemicals such as bisphenol A (BPA) and phthalates, which have been linked to endocrine disorders in both wildlife and humans (Flaws *et al.*, 2020). In Ghana, research by Coletta *et al.* (2023) revealed that water samples from plastic-polluted areas had elevated levels of these chemicals, which could have long-term health implications for communities relying on these water sources for drinking and irrigation. In addition, floating plastic waste creates breeding grounds for mosquitoes and other disease-carrying organisms, increasing the prevalence of vector-borne diseases such as malaria and dengue fever (Bachman, 2020). Efforts to address plastic pollution in Ghana have been growing, but significant challenges remain.

The National Plastic Management Policy (2020) was introduced to promote plastic recycling and reduce single-use plastics, but enforcement has been inconsistent (Wang *et al.*, 2022). Some community-based initiatives, such as those led by Plastic Punch and Green Ghana, have helped raise awareness and organize clean-up campaigns (Ebhaleme, 2022). However, studies indicate that plastic waste generation continues to outpace these efforts, highlighting the need for more sustainable waste management solutions (Gilson & Garrick, 2024). To effectively tackle plastic pollution, a multi-faceted approach is necessary. Stricter waste management regulations, investment in

biodegradable alternatives, and expanded public education campaigns on responsible plastic use could significantly reduce pollution levels.

## **2.8 Challenges in Managing Plastic Waste**

Managing plastic waste remains a significant environmental challenge in many developing nations, including Ghana, despite various waste management strategies aimed at mitigating pollution (Hira *et al.*, 2022). The persistence of plastic waste in water bodies is primarily driven by inadequate waste collection systems, weak enforcement of environmental regulations, and limited public awareness (Jambeck *et al.*, 2023). Studies indicate that in urban areas of Ghana, less than 40% of solid waste is collected correctly, with a considerable portion either ending up in open dumps or being washed into rivers and lakes, exacerbating environmental degradation (Ichipi, 2023). Furthermore, informal disposal methods such as open burning and indiscriminate dumping worsen the situation, contributing to air pollution and contaminating freshwater resources (Njoku *et al.*, 2023).

Although Ghana has introduced measures such as the National Plastic Management Policy (2020) to promote recycling and reduce plastic pollution, the implementation and enforcement of these policies remain inconsistent (Addo-Fordwuor & Seah, 2024). A study by Mensah (2022) found that over 70% of surveyed businesses in Accra were either unaware of or non-compliant with existing regulations governing plastic waste management. This lack of compliance is often due to insufficient monitoring and limited penalties for violations, which undermine the effectiveness of regulatory frameworks. In contrast, countries such as Rwanda have successfully implemented strict plastic bag bans, leading to significant reductions in plastic pollution (Rakubu, 2023).

Public perception and behavioural practices also contribute to the plastic waste crisis. Many communities, particularly in low-income areas, lack access to adequate waste disposal facilities and have limited knowledge about the long-term environmental impacts of plastic waste (Mensah, 2024). A study by Anbazu *et al.* (2022) revealed that 60% of respondents in Accra admitted to improperly disposing of plastic waste due to the absence of convenient disposal alternatives. Moreover, cultural attitudes often place the responsibility of waste management solely on municipal authorities rather than recognizing it as a collective societal duty (Geldreich, 2020). This highlights the need for extensive public education campaigns and community engagement initiatives to encourage responsible waste disposal practices. Recycling efforts in Ghana remain underdeveloped despite the growing urgency to manage plastic waste sustainably. Anbazu *et al.* (2022) found that only 2% of plastic waste in Ghana is currently recycled, with the majority being landfilled or abandoned in the environment. Limited access to recycling infrastructure, inadequate financial investment, and weak market demand for recycled products are key factors hindering the growth of the recycling sector (Jonathan *et al.*, 2023). By contrast, European nations such as Germany have achieved recycling rates of over 60% due to well-established waste segregation systems, financial incentives for recycling, and strong government policies supporting circular economies (Serpe *et al.*, 2025).

Addressing plastic pollution in Ghana requires a multi-dimensional approach that integrates stringent policy enforcement, investment in waste management infrastructure, and increased public awareness. Expanding waste collection services, particularly in underserved areas, could significantly reduce the amount of plastic waste entering water bodies (Wright *et al.*, 2024). In addition, offering incentives for businesses to adopt biodegradable packaging alternatives and supporting the growth of the recycling

industry could drive long-term improvements in plastic waste management (Moshood *et al.*, 2022). Community-driven programs, such as waste segregation initiatives and periodic clean-up campaigns, have also been identified as effective strategies for reducing plastic pollution and fostering a culture of environmental responsibility (Akande, 2023).

## **2.9 Health Risks Associated with Contaminated Water**

Access to clean water is essential for human health, yet many communities, particularly in developing countries like Ghana, continue to struggle with water contamination (Baddianaah *et al.*, 2024). Polluted water sources pose serious health risks, ranging from gastrointestinal infections to long-term conditions like reproductive disorders and even cancer due to the accumulation of toxic substances (Barinova *et al.*, 2020; Singh *et al.*, 2022). Heavy metals such as lead, mercury, and arsenic, which are often present in water sources polluted by industrial waste and mining activities, have been linked to kidney damage, cardiovascular diseases, and developmental delays in children (Lawal *et al.*, 2021; Munir *et al.*, 2021). Research in Ghana by Jonathan *et al.* (2023) found that lead and cadmium levels in groundwater exceeded WHO safety limits, increasing the risk of chronic diseases for local populations. Despite growing awareness of these dangers, there is still a major gap in water quality monitoring and access to safe drinking water. One of the biggest concerns is microbial contamination, which remains a leading cause of waterborne diseases. Harmful bacteria such as *Escherichia coli*, *Salmonella*, and *Vibrio cholerae* often find their way into water sources due to poor sanitation, untreated sewage discharge, and agricultural runoff (Mahagamage *et al.*, 2020; Madhav *et al.*, 2020). Studies in Ghana highlight the severity of the problem. Yeboah *et al.* (2022) reported that 65% of water sources tested in Accra contained faecal coliform bacteria, increasing the risk of diarrheal diseases. Similarly, Mahagamage *et al.* (2020) found

that untreated water sources in Kumasi were a major factor in recurring cholera outbreaks, particularly during the rainy season when floodwaters spread contaminants. Despite these alarming findings, many rural communities still lack access to affordable and effective water purification methods. To combat microbial contamination, researchers have explored cost-effective and straightforward water treatment methods. Solar disinfection (SODIS), for example, has been found to reduce bacterial contamination by up to 99% when applied to household drinking water (Zahoor & Mushtaq, 2023). Another practical approach is the use of biosand filters, which have been successfully implemented in parts of Ghana to improve water quality (Amengor, 2024). While these solutions have proven effective in reducing infection rates, widespread adoption remains a challenge due to financial constraints and limited public awareness.

Beyond microbial risks, chemical pollutants such as nitrates and pesticides from agricultural runoff also threaten water safety. High nitrate levels in drinking water can cause methemoglobinemia, or "blue baby syndrome," which affects oxygen transport in infants (Santos *et al.*, 2024; Shaban *et al.*, 2020). A study by Abdallah and Mourad (2021) found that groundwater sources in farming communities in the Ashanti Region contained nitrate concentrations up to three times higher than the WHO-recommended limits, posing serious health risks. Similarly, Mensah *et al.* (2021) detected high levels of organochlorine pesticides in rivers supplying domestic water in the Volta Region, raising concerns about long-term effects on hormonal balance and reproductive health. While these issues are well-documented, weak regulations on pesticide use and poor wastewater management continue to exacerbate the problem (Whelan *et al.*, 2022). To address chemical contamination, researchers have been testing innovative and affordable water purification methods. Studies show that constructed wetlands and

biochar filtration can significantly reduce nitrate and pesticide levels in polluted water sources (Malyan *et al.*, 2021). In Ghana, phytoremediation using plants like *Eichhornia crassipes* (water hyacinth) to absorb pollutants has shown promising results in improving water quality in contaminated lakes and rivers (Abdallah *et al.*, 2024).

Another major health risk comes from heavy metal contamination, especially in areas affected by mining. A study by Owusu *et al.* (2024) in southwestern Ghana found that mercury levels in rivers near small-scale mining sites were five times higher than WHO safety limits. Long-term mercury exposure is known to cause neurological disorders, birth defects, and kidney failure (Bibi *et al.*, 2023). Similarly, arsenic contamination, commonly associated with gold mining, has been found in groundwater sources across the country (Khosravi-Darani *et al.*, 2024). Palma-Lara *et al.* (2020) reported that prolonged arsenic exposure has led to increased cases of skin diseases and cancer among affected populations. Despite the health risks, weak enforcement of mining regulations and inadequate waste management continue to allow these pollutants to spread unchecked. To combat heavy metal contamination, researchers have tested low-cost remediation techniques. One promising approach is the use of bioadsorbents, such as coconut husk biochar, to remove heavy metals from water. Amoah-Oppong *et al.* (2024) found that this method effectively reduced mercury and arsenic concentrations in mining-affected rivers in Ghana, making the water safer for human consumption.

In addition, constructed wetlands with specific plant species, such as *Typha latifolia*, have been used successfully to filter heavy metals from polluted water (Mensah *et al.*, 2022). While these solutions are promising, large-scale implementation requires investment in infrastructure and stronger environmental policies. The burden of unsafe water disproportionately affects vulnerable populations, including children, pregnant

women, and those with weakened immune systems. According to UNICEF (2021), more than 70% of childhood deaths from diarrheal diseases in sub-Saharan Africa are directly linked to contaminated water and inadequate sanitation. A study by Pouramin *et al.* (2020) found that women in rural Ghana, who are primarily responsible for collecting and using water, face higher exposure to contaminated sources, leading to increased maternal and neonatal health complications. Similarly, Boateng *et al.* (2022) found that malnourished children in northern Ghana who consumed polluted water had significantly higher rates of stunted growth and weakened immune systems. These findings highlight the urgent need for sustainable water management solutions that prioritize the most vulnerable populations.

Addressing water-related health risks requires a multi-faceted approach. Strengthening environmental regulations, investing in modern water treatment technologies, and expanding access to safe drinking water are all critical steps in ensuring public health (Kwaah, 2023). On a local level, promoting household-level purification methods such as chlorination, filtration, and solar-powered purification has been shown to reduce microbial contamination significantly (Boateng *et al.*, 2022). Research indicates that decentralized water treatment systems, such as community-based solar-powered purification stations, have led to a 40% reduction in diarrheal disease cases in rural communities (Falk *et al.*, 2022).

## **2.10 Waterborne Diseases Linked to Contaminated Freshwater**

Waterborne diseases continue to pose significant public health risks in Ghana, particularly in communities that rely on untreated surface water for drinking and domestic use (Yeboah *et al.*, 2024). Contaminated freshwater sources serve as reservoirs for various microbial pathogens, leading to the spread of diseases such as

cholera, typhoid fever, dysentery, and diarrhoea (Mensah, 2022; Boahen & Owusu, 2023). These diseases are primarily transmitted through the ingestion of water contaminated with faecal matter, often due to poor sanitation, inadequate waste management, and agricultural runoff (Alegbeleye & Sant'Ana, 2020). Several studies have highlighted the link between poor water quality and the prevalence of waterborne diseases in Ghana. A study by Thani (2023) revealed that over 70% of water samples collected from rural communities contained *Escherichia coli*, indicating faecal contamination. Similarly, Leandro *et al.* (2022) found that the 2014 cholera outbreak in Ghana, which recorded over 28,000 cases, was mainly due to the consumption of unsafe water in urban slums where sanitation facilities were inadequate. Research by Woolf *et al.* (2023) further established that exposure to contaminated water sources increases the risk of gastrointestinal infections, with children under five years old being the most vulnerable group.

Ashanti Region, a significant freshwater resource in Ghana, has also been found to harbour microbial contaminants that pose health risks to local communities. Mensah *et al.* (2022) identified high concentrations of *Salmonella* and *Vibrio cholerae* in the lake, particularly during the rainy season when surface runoff increases bacterial loads. This contamination has been associated with recurrent cases of diarrhoea and other waterborne illnesses in settlements around the lake. A study by Tariq and Mushtaq (2023) reported that boreholes and wells in the lake's vicinity exhibited high total coliform counts, suggesting widespread microbial pollution that threatens the safety of drinking water. Addressing these waterborne diseases requires targeted interventions to improve water quality and sanitation infrastructure. Studies have demonstrated the effectiveness of household water treatment methods such as chlorination, filtration, and

solar disinfection (SODIS) in reducing microbial loads (Freitas *et al.*, 2021; Rosa e Silva *et al.*, 2022).

In Ghana, community-based initiatives such as the Safe Water Network have significantly improved access to potable water, thereby reducing waterborne disease incidence in affected areas (Boateng *et al.*, 2022). A recent study by Carter (2021) emphasized that strengthening rural water supply systems and integrating simple, cost-effective purification techniques can drastically lower microbial contamination levels in domestic water sources. Despite these interventions, challenges remain in ensuring sustainable access to clean water. Many rural and peri-urban communities still lack proper wastewater management systems, leading to continued contamination of freshwater sources. Climate change has further exacerbated the situation, with extreme weather events such as flooding increasing the spread of microbial pathogens across wider areas (UNICEF, 2021; Yeboah *et al.*, 2024). In addition, the lack of enforcement of water quality regulations and insufficient investment in sanitation infrastructure have hindered progress in reducing waterborne diseases (Olowoyo *et al.*, 2024). A holistic approach involving government agencies, health institutions, and local communities is necessary to mitigate the risks associated with contaminated freshwater. This includes enforcing stricter water quality standards, expanding access to improved sanitation facilities, and promoting public education on safe water practices (Duku *et al.*, 2024).

## **2.12 Impact of Water Pollution on Aquatic Life**

Water pollution has devastating effects on aquatic life, disrupting ecosystems and threatening biodiversity. Contaminants such as heavy metals, microplastics, and excessive nutrients alter the natural balance of freshwater bodies, affecting fish populations and other aquatic organisms (Bashir *et al.*, 2020; Wang *et al.*, 2021). These

pollutants often reduce oxygen levels, disturb pH balance, and introduce toxic substances into food chains, making survival difficult for many species. As a result, fish kills, declining biodiversity, and habitat destruction have been reported in several polluted water bodies worldwide. Research has shown that heavy metal contamination is a major factor affecting aquatic life in Ghana (Saah *et al.*, 2021). A study by Obodai *et al.* (2011) found high concentrations of mercury and lead in fish samples taken from the Tano and Pra rivers. These metals accumulate in fish tissues over time, making them unsafe for consumption and leading to severe ecological consequences. Similarly, Mensah *et al.* (2022) reported elevated cadmium levels in fish from the Weija Reservoir, with some exceeding the World Health Organization's (WHO) recommended safety limits.

Eutrophication, caused by excessive nutrient runoff from agricultural and domestic waste, has further worsened water pollution in Ghana. Kyei *et al.* (2023) observed frequent algal blooms in Lakes, which deplete oxygen levels in the water and suffocate fish. A study by Amoah Agyapong (2021) found that algal growth in the Volta Lake has led to mass fish deaths, reducing fish populations and affecting livelihoods. In addition, microplastic pollution has become a growing concern. A study by Saah *et al.* (2021) detected microplastic particles in the guts of fish from the Densu River, raising alarms about potential long-term effects on aquatic species and human consumers. The decline in fish populations due to pollution has economic and social consequences, particularly for fishing communities. Animah (2021) found that communities along the Volta Lake have experienced reduced fish catches over the past decade, leading to a loss of income and food insecurity. Many fishermen reported catching fewer fish, forcing them to travel farther or switch to alternative livelihoods.

Efforts to mitigate these challenges have included conservation projects and stricter pollution control measures. The Sustainable Fisheries Management Project (SFMP) in Ghana has helped introduce community-led initiatives to monitor water quality and promote sustainable fishing practices (Yeboah *et al.*, 2022). Meanwhile, research by Jonathan *et al.* (2023) suggests that restoring wetland ecosystems and enforcing pollution control laws can significantly improve water quality and aquatic biodiversity. However, more needs to be done to protect freshwater ecosystems. Weak enforcement of environmental laws and inadequate waste management continue to threaten water quality in Ghana (Yeboah *et al.*, 2022).

## **2.12 Socioeconomic Implications of Water Pollution**

Water pollution has far-reaching consequences that go beyond environmental degradation. It directly impacts the economy, public health, and the livelihoods of communities that depend on freshwater bodies for fishing, agriculture, and tourism (Raihan, 2023). In Ghana, where many people rely on water sources like Lake Bosomtwe, the Volta River, and other freshwater bodies, pollution threatens both income generation and food security (Kyei *et al.*, 2023). The presence of pollutants such as heavy metals, microplastics, and excessive nutrients has led to declining fish stocks, loss of tourism revenue, and increased healthcare costs, making it a pressing issue that requires immediate attention (Alegbeleye & Sant'Ana, 2020; Mensah *et al.*, 2022).

One of the most visible economic consequences of water pollution is the decline in fish populations. Many fishing communities in Ghana depend on lakes and rivers for their livelihoods, but pollution has significantly reduced fish stocks. A study by Amengor (2024) found that heavy metal contamination in the Volta Lake led to a 30% decline in

fish catches over five years, forcing fishermen to travel farther into deeper waters, increasing operational costs. Also, Danso (2024) reported that excessive plastic waste and industrial pollutants in Ghana's major rivers have led to fish mortality and deformities, making them unsafe for consumption.

Tourism, another important source of income for many communities, has also suffered due to declining water quality (Amengor, 2024). Lake Bosomtwe, known for its scenic beauty and cultural significance, attracts thousands of visitors annually. However, research (Mostafa *et al.*, 2024) found that high levels of eutrophication caused by excessive nutrients from agricultural runoff and untreated wastewater have led to algal blooms, making the lake less attractive for recreational activities such as swimming, boating, and fishing. A survey by Mensah *et al.* (2022) revealed that 65% of tourists who had visited Lake Bosomtwe expressed concerns about its deteriorating water quality, with many saying they would not return if conditions did not improve. This decline in tourism affects hotels, restaurants, and tour operators, leading to job losses and reduced income for local businesses.

Beyond its economic impact, water pollution places a heavy burden on public health (Lin *et al.*, 2022). Contaminated water sources are linked to a rise in waterborne diseases such as cholera, typhoid, and dysentery. Saah *et al.* (2022) found that communities with poor access to clean water reported a 40% higher incidence of diarrheal diseases compared to those with well-maintained water supplies. Amoako *et al.* (2018) further noted that in areas where polluted water is the primary source for drinking and domestic use, there has been a significant increase in hospital admissions related to gastrointestinal infections. This not only increases medical expenses for

affected families but also puts pressure on Ghana's healthcare system, diverting resources from other essential health programs.

Agriculture, another key sector of Ghana's economy, is also affected by water pollution. Many farmers rely on rivers and lakes for irrigation, but polluted water can introduce harmful chemicals into the soil, reducing crop yields and affecting food safety. A study by Owusu et al. (2022) found that crops irrigated with water from heavily polluted sources had higher levels of heavy metals such as lead and cadmium, which can pose serious health risks to consumers. Farmers in affected areas reported a decline in productivity and difficulty selling their produce due to contamination concerns. This not only affects their income but also threatens Ghana's food security, as lower agricultural yields can lead to increased food prices and reduced availability of fresh produce.

Efforts to address these challenges have been met with varying degrees of success. Government initiatives such as the Sustainable Fisheries Management Project (SFMP) have aimed to improve fishing practices and monitor water quality, but enforcement remains weak (Finegold et al., 2019). Similarly, the introduction of waste management programs and policies to reduce plastic pollution has helped in some urban areas, but rural communities continue to struggle with inadequate waste disposal infrastructure. More investment is needed in community-based waste management solutions, stricter enforcement of environmental laws, and increased public awareness about the importance of protecting freshwater resources. Without urgent intervention, the economic and social costs of water pollution will continue to rise.

### 2.13 Strategies for Improving Water Quality

Ensuring safe and sustainable freshwater resources is a global priority, particularly in regions like Ghana, where water pollution presents serious environmental and public health challenges (Amuah *et al.*, 2022). Effective strategies to mitigate water contamination require a holistic approach involving policy interventions, technological innovations, and community participation. Existing literature highlights various approaches that have been successfully implemented in different parts of the world, including improved waste management systems, stricter enforcement of environmental regulations, public education campaigns, and investments in modern water treatment facilities (Danso, 2024; Duku *et al.*, 2024). These interventions, when well-coordinated, contribute significantly to preserving water quality and ensuring long-term sustainability. One of the most critical strategies for improving water quality is the enhancement of waste management systems.

Poor waste disposal, particularly in urban areas, is a leading cause of freshwater contamination. A study by Owusu-Sekyere *et al.* (2024) revealed that improper waste disposal accounts for approximately 60% of pollutants found in urban rivers in Ghana. To address this issue, various cities have introduced waste recycling programs and improved sewage infrastructure. In Kumasi, for instance, the introduction of a waste segregation and recycling initiative led to a 25% reduction in plastic waste entering local water bodies within two years (Mensah *et al.*, 2022). These findings underscore the need for nationwide adoption of similar initiatives to mitigate pollution. Another crucial approach involves the enforcement of environmental regulations. Weak regulatory oversight often results in industrial and agricultural contaminants being discharged into freshwater systems. Amuah *et al.* (2022) found that several industries along the Weija Dam discharged untreated effluents directly into the water,

significantly affecting its quality. However, countries that have implemented stricter regulatory frameworks have observed notable improvements. For example, in South Africa, enhanced enforcement of effluent discharge policies led to a 35% reduction in heavy metal contamination in key rivers over five years (Zulu, 2020). Strengthening monitoring mechanisms and imposing stricter penalties on violators could yield similar benefits in Ghana.

Public education and community engagement are also vital components of water conservation efforts. Many water pollution challenges stem from inadequate public awareness of proper waste disposal and sanitation practices. Amuah *et al.* (2022) conducted a study in communities around Lake Bosomtwe and found that households that received water conservation education were 40% less likely to dispose of waste improperly. Furthermore, community-led clean-up campaigns, such as the “Clean Volta Campaign,” have demonstrated success in mobilizing local fishermen and youth groups to remove plastic waste from the Volta River, improving water clarity and reducing pollution-related fish mortality (Kyei *et al.*, 2023).

Expanding such initiatives nationwide could foster greater public responsibility toward water conservation. Investing in modern water treatment technologies is another essential strategy for improving water quality (Obaideen *et al.*, 2022). Many freshwater sources in Ghana suffer from microbial contamination due to inadequate treatment facilities. According to Owusu-Sekyere *et al.* (2024), advanced water treatment plants with effective filtration and purification systems can significantly reduce contaminants, making water safe for consumption and agricultural use. In addition, low-cost filtration technologies such as biosand filters and solar disinfection methods have proven highly effective in rural areas (Obaideen *et al.*, 2022). A study by Amuah *et al.* (2022)

demonstrated that biosand filtration reduced bacterial contamination in rural water sources by 85%, significantly lowering cases of waterborne diseases. Expanding these technologies to underserved communities could substantially enhance water security and public health.

Furthermore, protecting and restoring natural ecosystems that serve as water sources is crucial. Wetlands, for example, play a significant role in filtering pollutants from runoff before they reach rivers and lakes. However, rapid urbanization and agricultural encroachment have degraded many wetland areas in Ghana. Anima Gyimah *et al.* (2020) found that wetland restoration efforts in the Densu River Basin led to a 20% improvement in water quality indicators, such as turbidity and dissolved oxygen levels.

#### **2.14 Summary of Literature Review**

The literature reviewed identifies key environmental challenges affecting Lake Bosomtwe, including physicochemical pollution, microbial contamination, plastic waste, and related health risks. Scholars such as Adino (2024) and David Jr et al. (2022) have highlighted declining dissolved oxygen levels due to organic pollution, while Chuku et al. (2022) and Tenebe et al. (2022) reported high turbidity linked to erosion and illegal mining. Eli (2023) and Myers et al. (2023) drew attention to nutrient pollution and plastic waste, noting their impact on water quality and treatment costs. Although these studies provide useful insights, there remains a gap in identifying specific pollution sources and effective mitigation strategies tailored to the lake's context. Further research is needed to inform sustainable water quality management.

## **CHAPTER THREE**

### **RESEARCH METHODOLOGY**

#### **3.1 Introduction**

This chapter presents the research methodology employed to assess the health risks associated with selected contaminants in Lake Bosomtwe, Ghana, and compare these risks with those in other recreational ponds. The study integrates both field-based and laboratory analyses to determine the lake's physicochemical and microbial status, while a structured survey captures public perceptions and health implications.

#### **3.2 Research Design**

This study employed a cross-sectional approach to assess water contamination levels and associated health risks. The combination of structured surveys and water sample analysis provided a comprehensive understanding of human exposure and environmental conditions (Suryawan et al., 2025). A cross-sectional research design was used, allowing for the simultaneous collection of data on contamination levels and their potential health effects.

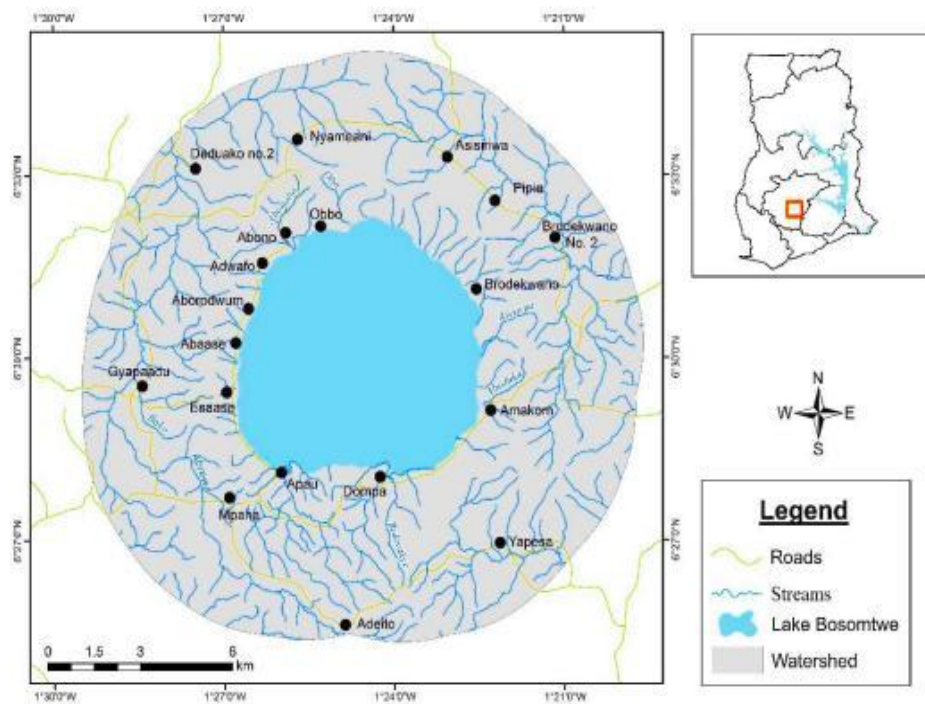
#### **3.3 Study Area**

##### **3.3.1 Overview of Lake Bosomtwe**

The study was conducted in Lake Bosomtwe, the largest natural lake in Ghana, located in the Ashanti Region within the Amansie East and Bosomtwe districts. Formed by a meteorite impact, the lake spans approximately 49 km<sup>2</sup> and reaches a maximum depth of 78 meters. It is situated between latitudes 6°30'N and 6°42'N and longitudes 1°24'W and 1°35'W (Peasah et al., 2023; Jonathan et al., 2023). Twenty-two (22) communities encircle the lake with an estimated population of 30,000, predominantly of the Asante ethnic group. Twi is the primary language spoken, and over 65% of the residents have

received formal education (GSS, 2021). The population is youthful, mainly, with about 58% under the age of 35, contributing to a dynamic labour force.

The economy of the area is mainly driven by agriculture, with over 70% of households involved in farming crops such as cocoa, maize, cassava, and vegetables. Fishing is also a key livelihood, employing nearly 60% of men in the surrounding communities (Amu-Mensah et al., 2020), with Tilapia and African catfish being the most harvested species. In addition to farming and fishing, local trade and tourism play significant roles in the local economy, supported by markets such as Abono and Kuntanase. The lake's cultural and spiritual significance to the Asante people has led to certain traditional restrictions on activities such as using motorized boats. As an endorheic lake with no natural outlet, Lake Bosomtwe is highly susceptible to pollution from agricultural runoff, human settlements, and recreational activities, posing serious risks to both environmental and public health.



**Figure 3.1 Map of Lake Bosomtwe**

### 3.4 Study Population and Sampling Techniques

#### 3.4.1 Target Population and Inclusion Criteria

The study focused on individuals who frequently interacted with Lake Bosomtwe, including residents and workers engaged in economic activities around the lake. This included fishermen, boat operators, food vendors, tour guides, and other local business owners. Participants were eligible if they were 18 or older and had at least one year of experience using the lake for domestic, recreational, or economic purposes. Individuals with pre-existing health conditions unrelated to water contamination were excluded to minimize potential confounding factors.

#### 3.4.2 Sample Size Determination

The sample size for the study was determined using the formula originally developed by Yamane (1967) and later adapted by Hasan and Kumar (2024) for sample size estimation in survey-based research. The formula is expressed as:

$$n = \frac{N}{1+N(e)^2}$$

Where:

n = required sample size

N = total population size

e = margin of error (level of precision)

Given that the estimated population of lake users around Lake Bosomtwe is approximately 1,000, and a 5% margin of error (0.05) was adopted at a 95% confidence level, the sample size was calculated as follows:

$$n = \frac{10000}{1+10000(0.05)^2} = \frac{10000}{1+26} = \frac{10000}{26} = 384.6$$

However, due to time, resource, and accessibility constraints, the study employed a sample size of 100 respondents. This number was considered adequate to obtain

representative and reliable data from different categories of lake users. The distribution of respondents is presented in Table 3.1 below.

**Table 3.1: Sample Frame for Lake Workers and Residents**

| Category              | Estimated Population (N <sub>i</sub> ) | Proportional Sample (n <sub>i</sub> ) |
|-----------------------|--|---------------------------------------|
| Residents             | 4,500                                  | 45                                    |
| Fishermen             | 2,000                                  | 20                                    |
| Boat Operators        | 1,000                                  | 10                                    |
| Food Vendors          | 1,000                                  | 10                                    |
| Tour Guides           | 500                                    | 5                                     |
| Local Business Owners | 1,000                                  | 10                                    |
| <b>Total</b>          | <b>10,000</b>                          | <b>100</b>                            |

(Source: GSS, 2021)

The proportional sample (n<sub>i</sub>) for each category was calculated using;

$$n_i = \frac{(N_i)}{(N)} \times n \dots\dots\dots \text{Eq.1}$$

Where;

n<sub>i</sub> = Sample size for each category

N<sub>i</sub> = Population of each category

N = Total estimated population (10,000)

n = Total sample size (100)

### 3.4.3 Sampling Techniques

The study employed a stratified sampling technique to ensure a representative selection of participants. This approach enhanced the accuracy and generalizability of the findings (Peasah *et al.*, 2023). The population was categorized into distinct subgroups based on their interaction with the lake, namely residents, fishermen, boat operators, food vendors, tour guides, and local business owners. A proportional allocation strategy was used to determine the sample size for each stratum, after which participants were randomly selected. Structured questionnaires were then administered to collect data from each subgroup.

### **3.5 Data Collection Tools and Methods**

The study employed structured questionnaires as the primary data collection tool to gather information from respondents. Questionnaires allowed for standardized data collection, ensuring consistency and reliability in responses (Creswell & Creswell, 2018).

#### **3.5.1 Structured Questionnaires**

Structured questionnaires were developed to gather data on respondents' demographics, water use patterns, health experiences, and perceptions of contamination risks. These were administered to lake workers. The standardized format minimized interviewer bias and enabled consistent, quantitative analysis (Bryman, 2016). Questionnaire items were adapted from prior studies on water contamination and health risks to ensure validity and contextual relevance (WHO, 2021).

### **3.6 Water Samples and Sampling Techniques**

Fifty (50) water samples were collected from Lake Bosomtwe to ensure broad coverage of key areas, including fishing zones, domestic water-use sites, and undisturbed sections. This sample size follows established environmental sampling practices. It is consistent with similar studies, such as Anning et al. (2020), who used 48 samples in Lake Volta, and Bizikova et al. (2020), who collected 50 samples in the Densu Basin. This approach ensures reliable representation of water quality across different locations within the lake.

### **3.7 Laboratory Analysis**

#### ***3.7.1 Physicochemical Parameters Analysis***

The analysis of physicochemical parameters was conducted following standard laboratory procedures to ensure accuracy and reliability. All instruments were calibrated correctly, and analytical-grade reagents were used with strict quality control measures.

#### **Electrical Conductivity (EC) and Total Dissolved Solids (TDS)**

Electrical Conductivity (EC) was measured using a Hanna Instruments HI 9033 Conductivity Meter (manufactured by *Hanna Instruments, Woonsocket, Rhode Island, USA; made in Romania*), calibrated with a 1413  $\mu\text{S}/\text{cm}$  Potassium Chloride (KCl) Standard Solution (*Hanna Instruments, Code HI7031L, Romania*). Total Dissolved Solids (TDS) were determined using a Hanna Instruments HI 8734 TDS Meter (manufactured by *Hanna Instruments, USA; made in Italy*), calibrated with a 1000 mg/L Sodium Chloride (NaCl) Standard Solution (*Hanna Instruments, Code HI7037L, Romania*). Calibration and analysis were conducted under controlled laboratory conditions to ensure precision and consistency in readings.

#### **Turbidity and pH**

Turbidity was measured using a Hach 2100Q Portable Turbidimeter (*manufactured by Hach Company, Loveland, Colorado, USA*). The instrument was calibrated with formazin primary turbidity standards of 0.02 NTU, 20 NTU, and 100 NTU (*Hach Company, Calibration Standards Set, Code 2461-SC, USA*) to ensure accurate and reliable assessment of water clarity.

pH levels were determined using a Mettler Toledo SevenCompact pH Meter (S210 model) (*manufactured by Mettler Toledo GmbH, Schwerzenbach, Switzerland*). The instrument was calibrated using buffer solutions of pH 4.01, 7.00, and 10.00 (*Mettler*

*Toledo Buffer Solutions, Codes 51302047, 51302042, and 51302044, Switzerland*), to obtain precise and reproducible readings.

### **Spectrophotometric Analysis of Fluoride, Iron, Sulfates, Nitrates, and Nitrites**

A Hach DR 6000 UV–Vis Spectrophotometer (manufactured by Hach Company, Loveland, Colorado, USA) was employed for the quantitative analysis of key ions in water samples using standard Hach methods. Fluoride concentration was determined using the SPADNS colorimetric method (Hach Method 8029) with absorbance measured at 570 nm, employing the SPADNS Reagent Set (Hach Code 10553-99, USA). Iron was analyzed using the 1, 10-Phenanthroline method (Hach Method 8008) with measurement at 510 nm, using FerroVer Iron Reagent Powder Pillows (Hach Code 21057-69, USA).

Sulfates were determined using the Turbidimetric method (Hach Method 8051) with absorbance read at 420 nm, using Sulfate Reagent Set (Hach Code 8051, USA). Nitrates and Nitrites were analyzed using the Cadmium Reduction method (Hach Method 8039) and the Diazotization method (Hach Method 8507), respectively, with absorbance measured at 543 nm. Corresponding NitraVer 5 (Hach Code 21061-69) and NitriVer 3 (Hach Code 21076-69) reagent powder pillows were used.

### **Arsenic Determination via Atomic Absorption Spectrometry (AAS)**

Arsenic concentrations were determined using a PerkinElmer AAnalyst 800 Atomic Absorption Spectrometer equipped with a graphite furnace (manufactured by PerkinElmer Inc., Waltham, Massachusetts, USA). Each 50 mL water sample was digested with 5 mL of 65% nitric acid (HNO<sub>3</sub>) (analytical grade, Merck, Darmstadt, Germany) and heated at 95°C for 30 minutes, following the procedure described in APHA (2017) and USEPA Method 200.9 (1994).

Calibration was performed using Arsenic Standard Solution (1000 mg/L, TraceCERT®, Sigma-Aldrich, Code 119778, Germany). Working calibration standards of 0, 10, 25, and 50 µg/L were prepared by serial dilution with deionized water (resistivity  $\geq 18.2 \text{ M}\Omega\cdot\text{cm}$ ). Analysis was conducted at a wavelength of 193.7 nm, and all measurements were quality-controlled through reagent blanks, standard reference checks, and duplicate runs to ensure precision and reliability.

### **Chlorine Analysis (Free, Combined, and Total)**

Chlorine concentrations (free, combined, and total) were determined following the DPD (N,N-diethyl-p-phenylenediamine) Colorimetric Method as described by APHA (2017), Method 4500-Cl G. Free chlorine was analyzed by mixing 10 mL of the water sample with 1 mL of DPD reagent powder pillow (Hach Company, Loveland, Colorado, USA; Cat. No. 2105569). The absorbance was then read at 515 nm using a Hach DR 900 portable colorimeter (Hach Company, Loveland, Colorado, USA), calibrated with factory-supplied chlorine check standards prior to measurement to ensure accuracy.

For combined and total chlorine determination, 0.2 M potassium iodide (KI) solution was added to the reacted sample, followed by titration with 0.01 M sodium thiosulfate ( $\text{Na}_2\text{S}_2\text{O}_3$ ) until the pink color disappeared. All reagents used were analytical grade (Merck, Darmstadt, Germany) and prepared with deionized water (resistivity  $\geq 18.2 \text{ M}\Omega\cdot\text{cm}$ ). The sodium thiosulfate solution was standardized using potassium dichromate ( $\text{K}_2\text{Cr}_2\text{O}_7$ ) before use.

### **3.7.2 Quality Control and Assurance**

Laboratory analyses were conducted under strict quality control (QC) and quality assurance (QA) protocols to ensure accuracy, precision, and reproducibility of data. All analytical instruments, including the Hach DR 900 colorimeter (Hach Company,

Loveland, Colorado, USA), PerkinElmer AAnalyst 800 Atomic Absorption Spectrometer (PerkinElmer, Waltham, Massachusetts, USA), and Hach DR 6000 UV Vis spectrophotometer (Hach Company, USA), were calibrated daily before sample analysis. Calibration was performed using Certified Reference Materials (CRMs) and standard solutions obtained from Merck (Darmstadt, Germany) and Sigma Aldrich (St. Louis, Missouri, USA).

Validation of analytical accuracy was ensured through the inclusion of method blanks, triplicate samples, and matrix spike recoveries for every batch of 10 samples. Acceptable recovery rates ranged between 90–110%, and relative standard deviation (RSD) values below 5% were maintained for replicate analyses. Deionized water with resistivity not less than 18.2 M $\Omega$ ·cm was used for all reagent and sample preparations to prevent contamination. All reagents used were analytical grade with purity  $\geq$ 99%, and glassware was acid washed with 10% HNO<sub>3</sub> and rinsed thoroughly with deionized water prior to use. For trace metal analyses, continuing calibration verification (CCV) and method detection limit (MDL) checks were performed according to APHA Standard Methods (2017, 23rd Edition).

### **3.7.3 Heavy Metal Analysis Using Atomic Absorption Spectroscopy (AAS)**

The concentration of heavy metals in the water samples was determined using a PerkinElmer AAnalyst 800 Atomic Absorption Spectrophotometer (PerkinElmer, Waltham, Massachusetts, USA), following the procedure described by Nallakukkala and Lal (2022). The instrument was equipped with hollow cathode lamps specific for each metal and operated under optimized conditions for wavelength, slit width, and lamp current.

Calibration was performed using multi-element standard solutions prepared from 1000 mg/L stock standards (Merck, Darmstadt, Germany) that are traceable to the National Institute of Standards and Technology (NIST, USA). A five-point calibration curve (0, 5, 10, 20, and 50 µg/L) was constructed for each element, and the correlation coefficients (R<sup>2</sup>) for all metals were maintained at ≥0.999 to ensure accuracy. Quality control checks were performed using continuing calibration verification (CCV) standards after every 10 samples to monitor drift and instrument stability.

Each 50 mL water sample was digested with 5 mL of concentrated HNO<sub>3</sub> (65%, Merck, Germany) and heated at 95°C for 30 minutes before filtration and analysis. Blanks and triplicate determinations were included to ensure analytical precision and reproducibility. The concentration of each heavy metal was calculated using:

$$C = \frac{A - B}{m} \dots\dots\dots \text{eq 2}$$

Where:

**C** = concentration of the metal in the sample (mg/L)

**A** = absorbance of the sample

**B** = absorbance of the blank

**m** = slope of the calibration curve.

**Adjustment for Blank Correction**

$$C_{\text{corrected}} = \frac{R_{\text{sample}} \times R_{\text{blank}} \times DF}{V} \dots\dots\dots \text{eq 3}$$

Where:

R\_sample = AAS reading for the sample

R\_blank = AAS reading for the blank (deionized water or reagent blank)

**Detection Limits and Quantification Limits**

The Limit of Detection (LOD) and Limit of Quantification (LOQ) for each heavy metal were determined to assess the analytical sensitivity of the PerkinElmer AAnalyst 800 Atomic Absorption Spectrophotometer (PerkinElmer, Waltham, Massachusetts, USA).

LOD and LOQ were calculated according to APHA (2017, Method 3111B) using the following equations:

$$\text{LOD} = \frac{SD_{\text{blank}}}{m} \dots\dots\dots\text{eq 4}$$

$$\text{LOQ} = \frac{SD_{\text{blank}}}{m} \dots\dots\dots\text{eq 5}$$

**Where:**

SD<sub>blank</sub> = Standard deviation of 10 replicate blank measurements

m = Slope of the calibration curve for each metal

The calculated LOD and LOQ values for all metals were within acceptable analytical ranges as recommended by APHA (2017), ensuring that even trace-level concentrations were reliably detected and quantified.

**3.7.4 Microbial quality**

Microbial quality was assessed to detect and quantify pathogenic bacteria, focusing on *Total coliforms*, *Escherichia coli* (*E. coli*), *Vibrio* spp., and *Salmonella* spp., following the Standard Methods for the Examination of Water and Wastewater (APHA, 2017). Results were expressed as colony-forming units per 100 mL (CFU/100 mL).

Total Coliforms and *E. coli* were determined using the membrane filtration technique (APHA Method 9222B and 9222D). A 100 mL aliquot of each water sample was filtered through a 0.45 µm membrane filter (Millipore, USA) using a sterile filtration unit. The membrane was placed on M-Endo agar LES (Oxoid, UK) for total coliforms and m-FC agar (Himedia, India) for *E. coli*. Plates were incubated at 35°C ± 0.5°C for 24 hours (total coliforms) and 44.5°C ± 0.2°C for 24 hours (*E. coli*). Colonies showing a metallic sheen on M-Endo agar were identified as total coliforms, while blue colonies on m-FC agar were confirmed as *E. coli*.

*Vibrio* spp. detection followed APHA Method 9260B. Samples (10 mL) were pre-enriched in Alkaline Peptone Water (Oxoid, UK) and incubated at 37°C for 6–8 hours. Enriched samples were streaked onto Thiosulfate Citrate Bile Salts Sucrose (TCBS) agar (Oxoid, UK) and incubated at 37°C for 24 hours. Yellow colonies indicated *Vibrio cholerae*, while green colonies suggested *Vibrio parahaemolyticus*. Suspected isolates were confirmed using biochemical tests including oxidase, indole, and triple sugar iron (TSI) reactions.

*Salmonella* spp. detection followed APHA Method 9260C. Samples were pre-enriched in Buffered Peptone Water (BPW, Merck, Germany) and incubated at 37°C for 18–24 hours, then selectively enriched in Selenite F broth (Oxoid, UK) and incubated at 37°C for another 24 hours. Enriched cultures were streaked onto Xylose Lysine Deoxycholate (XLD) agar (Himedia, India) and incubated at 37°C for 24 hours. Red colonies with black centers were presumptively identified as *Salmonella* spp., confirmed through Triple Sugar Iron (TSI) and urease biochemical tests. Microbial loads were quantified using the membrane filtration count, expressed as CFU per 100 mL, and calculated using Eq. 5:

$$\text{CFU}/100\text{mL} = \frac{\text{Number of colonies} \times \text{Dilution factor}}{\text{Volume of sample filtered (mL)}} \dots\dots\dots\text{eq 5}$$

Where:

N = number of bacterial colonies counted

V = volume of sample filtered (mL)

### **3.8 Data Analysis and Health Risk Assessment**

#### **3.8.1 Statistical Analysis**

Data from questionnaires, physicochemical assessments, and microbial analyses were processed using SPSS (Version 25) and Microsoft Excel. Questionnaire responses were analyzed descriptively using frequencies and Percentages (%) to assess public

perceptions of water quality and associated health symptoms. The Chi-Square test examined associations between water contamination and reported illnesses. Physicochemical and microbial data were evaluated across sampling sites using Analysis of Variance (ANOVA), with the Kruskal-Wallis test as a non-parametric alternative when assumptions of normality or homogeneity of variance were not met. Correlation analysis was employed to assess relationships between physicochemical parameters and microbial contamination. Additionally, binary logistic regression was used to estimate the likelihood of waterborne illness based on exposure levels. Graphical representations, including bar charts and scatter plots, were generated in Excel to illustrate spatial trends in contamination levels.

### 3.8.2 Health Risk Assessment

Human health risk assessment methodologies for aquatic ecosystems have been well-documented in the literature (Zhang et al., 2020; USEPA, 1989, 2005; Khan et al., 2023). Among the common exposure pathways to contaminants in water are ingestion and dermal absorption (USEPA, 1989; Khan et al., 2023). The United States Environmental Protection Agency (USEPA) Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual (Part A), published in 1989, provides standardized numerical expressions to quantify potential health risks associated with these exposure routes (USEPA, 1989). These methodologies facilitate the estimation of exposure doses and the subsequent evaluation of health risks posed by toxic substances in aquatic environments.

#### Exposure Dose through Ingestion

$$D_{ing} = \frac{C_{water} \times IR \times EF \times ED}{BW \times AT} \dots\dots\dots eq 7$$

#### Exposure Dose through Dermal Absorption

$$D_{derm} = \frac{C_{water} \times SA \times KP \times ED \times EF \times ED \times CF}{BW \times AT} \dots\dots\dots eq 8$$

Where:

In the human health risk assessment for aquatic environments, the exposure dose through ingestion ( $D_{ing}$ ) and dermal absorption ( $D_{derm}$ ) was calculated using key exposure parameters such as the concentration of metals in water ( $C_{water}$ , in  $\mu\text{g/L}$ ), ingestion rate (IR), exposure frequency (EF), exposure duration (ED), body weight (BW), and averaging time (AT). Specifically, IR was taken as 2.2 L/day for adults and 1.8 L/day for children; EF was 350 days/year; ED was 70 years for adults and 6 years for children; BW was 70 kg for adults and 15 kg for children; and AT was 25,550 days for adults and 2,190 days for children. For dermal exposure, additional parameters included the exposed skin area (SA: 18,000  $\text{cm}^2$  for adults and 6,600  $\text{cm}^2$  for children), exposure time (ET: 0.58 h/day for adults and 1 h/day for children), a unit conversion factor (CF: 0.001  $\text{L/cm}^3$ ), and the dermal permeability coefficient ( $K_p$ ), which varied by metal— $1.0 \times 10^{-3}$  cm/h for Fe,  $4.0 \times 10^{-3}$  for Pb,  $6.0 \times 10^{-3}$  for Zn,  $2.0 \times 10^{-3}$  for Cr, and  $4.0 \times 10^{-3}$  for Ni (USEPA, 1989, 2005; Wu et al., 2009; Liang et al., 2011). To evaluate potential non-carcinogenic health risks, the calculated exposure doses were compared with their respective reference doses (RfD). The ratio of these values yielded the hazard quotient (HQ), which represented the likelihood of adverse health effects from a single element via a specific route of exposure.

$$HQ_{ing/derm} = \frac{D_{ing/derm}}{RfD_{ing/derm}} \dots\dots\dots \text{eq 10}$$

Where, the hazard quotient via ingestion or dermal contact ( $HQ_{ing/derm}$ ) was determined by dividing the estimated exposure dose by the corresponding oral or dermal reference dose ( $RfD_{ing/derm}$ ), which was expressed in  $\mu\text{g/kg/day}$ . The reference dose values for ingestion and dermal contact were obtained from established literature by Zhang et al. (2020), USEPA (1989), Khan et al. (2023), Chen and Ma (2021). To assess the cumulative non-carcinogenic risk from multiple elements, the individual hazard

quotients calculated for each element were summed to derive the hazard index (HI), as recommended by the USEPA (1989).

$$HI = \sum_{i=1}^n HQ_{ing/derm} \dots\dots\dots eq 11$$

where, the hazard index via ingestion or dermal contact ( $HI_{ing/derm}$ ) represented the cumulative non-carcinogenic risk from exposure to multiple contaminants through a specific route. To estimate the daily exposure level of an individual to a contaminant over an extended period, the chronic daily intake (CDI) was calculated.

$$CDI_{ing} = C_{water} \times \frac{DI}{BW} \dots\dots\dots eq 12$$

Where chronic daily intake (CDI) was calculated using the concentration of trace metals in water ( $C_{water}$ , in  $\mu\text{g}/\text{kg}$ ), the average daily intake of water ( $DI$ ), and the body weight of the exposed individual ( $BW$ ). To assess the potential carcinogenic risk from exposure to toxic metals, the cancer risk (CR) was computed using a formula that combined the CDI and the cancer slope factor (SF).

$$\text{Cancer Risk} = CDI_{ing} \times (SF_{ing}) \dots\dots\dots eq 13$$

Where the cancer slope factor ( $SF_{ing}$ ) represents the rate at which a contaminant increases the risk of cancer, the  $SF_{ing}$  for lead (Pb) is 8.5, and for chromium (Cr), it is  $5.0 \times 10^2 \text{ mg}/\text{kg}/\text{day}$  (USEPA 1989, 2005; Kaluai, 2022; da Silva et al., 2023).

### 3.9 Quality Control and Quality Assurance (QA/QC)

To ensure data accuracy and reliability, rigorous QA/QC protocols were followed during sampling and laboratory analysis. Prior to sample collection, all bottles were pre-rinsed with deionized water to prevent contamination. Field blanks and duplicate samples were used to verify measurement accuracy and detect external contamination. Analytical instruments were calibrated before and after use with certified standards to maintain precision. Triplicate testing was performed for microbial analyses to enhance

reproducibility. Certified reference materials (CRMs) were employed in physicochemical and heavy metal assessments to validate analytical accuracy.

### **3.10 Ethical Considerations**

Ethical approval was obtained from the Committee on Human Research, Publication and Ethics, Kwame Nkrumah University of Science and Technology (*KNUST*), ensuring compliance with research ethics (*CHREP/AP/188/21*). Participants provided informed consent, and all data were anonymized to maintain confidentiality.

## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.0 Introduction

This chapter presents results and discussion of the findings of the study in line with the specific objectives set out in Chapter One. These objectives were to assess the physicochemical status of Lake Bosomtwe, determine the levels of microbial contamination, and evaluate the health risks associated with consuming or being exposed to the contaminated water. Each section will examine the results of the established World Health Organization (WHO) guidelines for water quality, and the discussion will draw from existing research to provide a broader understanding of the implications of these findings.

#### 4.1 Physicochemical Parameters of Water Samples from Lake Bosomtwe

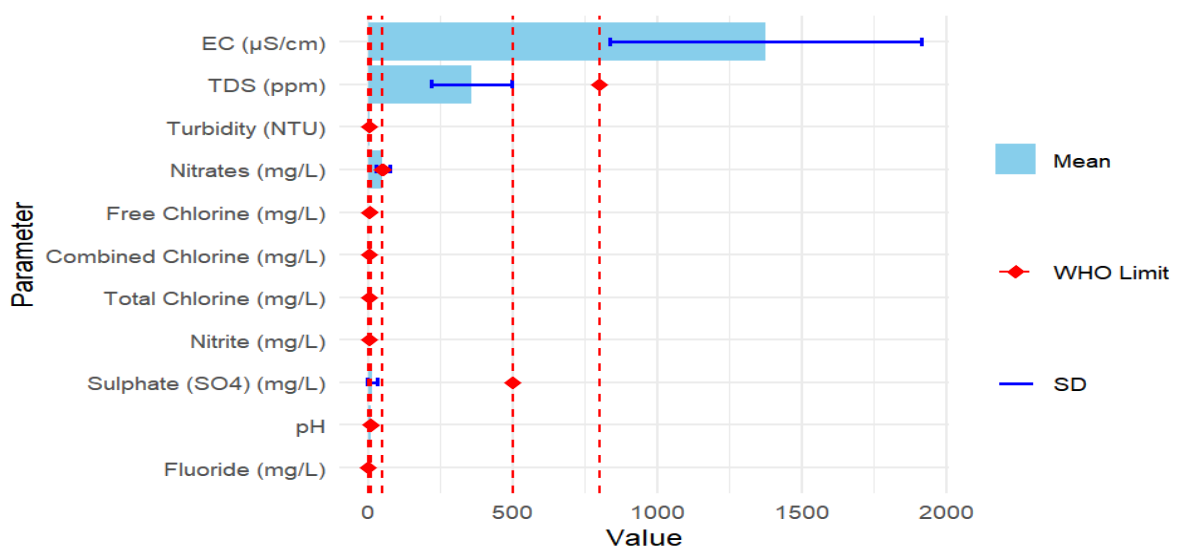
Table 4.1 presents the results of the physicochemical characteristics of water samples collected from various locations around Lake Bosomtwe. Electrical Conductivity (EC) values ranged from 299.1  $\mu\text{S}/\text{cm}$  (AB-1) to 1672  $\mu\text{S}/\text{cm}$  (PE-3), with a mean of 1374.23  $\mu\text{S}/\text{cm}$ . Total Dissolved Solids (TDS) ranged from 90.78 ppm (AB-1) to 433.8 ppm (P1-b), averaging 357.30 ppm. Turbidity levels varied from 0.98 NTU (AB-3) to 4.82 NTU (PE-3). Nitrate concentrations ranged from 24 mg/L to 74 mg/L, with the highest values recorded at P1-a and P2-a. Free chlorine levels were generally low (0.00–0.05 mg/L), and nitrite concentrations averaged 0.022 mg/L, well below critical limits. Arsenic concentrations ranged from 4  $\mu\text{g}/\text{L}$  to 91  $\mu\text{g}/\text{L}$ , with the highest at P1-a. Fluoride and sulphate concentrations were within WHO limits, ranging from 0.50–0.84 mg/L and 4–63 mg/L, respectively. The pH values ranged between 8.7 and 8.9, with a mean of 8.8, indicating slightly alkaline water. Iron was undetectable in most samples except for the P1 series, where 0.04 mg/L was recorded.

**Table 4.1: Physicochemical and Chemical Parameters of Water Samples**

| <b>Parameter</b>                   | <b>N</b> | <b>Mean</b> | <b>Std Dev</b> | <b>Min</b> | <b>25%</b> | <b>Median</b> | <b>75%</b> | <b>Max</b> |
|------------------------------------|----------|-------------|----------------|------------|------------|---------------|------------|------------|
| EC ( $\mu\text{S}/\text{cm}$ )     | 15       | 1374.23     | 540.38         | 299.1      | 1558.0     | 1648.0        | 1663.0     | 1672.0     |
| TDS (ppm)                          | 15       | 357.30      | 138.09         | 90.78      | 403.85     | 425.50        | 429.75     | 436.20     |
| Turbidity (NTU)                    | 15       | 3.33        | 1.24           | 0.98       | 3.32       | 3.69          | 4.13       | 4.82       |
| Nitrates (mg/L)                    | 5        | 48.96       | 24.81          | 24.0       | 24.80      | 48.00         | 74.00      | 74.00      |
| Free Chlorine (mg/L)               | 5        | 0.026       | 0.021          | 0.00       | 0.010      | 0.030         | 0.040      | 0.050      |
| Combined Chlorine (mg/L)           | 5        | 0.008       | 0.011          | 0.00       | 0.000      | 0.000         | 0.020      | 0.020      |
| Total Chlorine (mg/L)              | 5        | 0.034       | 0.030          | 0.00       | 0.010      | 0.030         | 0.060      | 0.070      |
| Nitrite (mg/L)                     | 5        | 0.022       | 0.008          | 0.01       | 0.020      | 0.020         | 0.030      | 0.030      |
| Arsenic ( $\mu\text{g}/\text{L}$ ) | 15       | 28.80       | 27.58          | 4.00       | 6.50       | 8.00          | 47.50      | 91.00      |
| Sulphate ( $\text{SO}_4$ ) (mg/L)  | 5        | 12.80       | 15.93          | 3.00       | 4.00       | 8.00          | 8.00       | 41.00      |
| pH                                 | 5        | 8.76        | 0.09           | 8.70       | 8.70       | 8.70          | 8.80       | 8.90       |
| Fluoride (mg/L)                    | 15       | 0.636       | 0.116          | 0.50       | 0.560      | 0.600         | 0.680      | 0.84       |
| Iron (Fe) (mg/L)                   | 15       | 0.008       | 0.017          | 0.00       | 0.000      | 0.000         | 0.000      | 0.04       |

#### 4.1.1 Key Observations and Interpretation of Physicochemical

The results presented in Figure 4.1 show the mean values and standard deviations of various water quality parameters in Lake Bosomtwe compared with WHO guideline limits. The electrical conductivity (EC) had a mean value of approximately 1400  $\mu\text{S}/\text{cm}$ , with a standard deviation of  $\sim 500$   $\mu\text{S}/\text{cm}$ . Total dissolved solids (TDS) were around 400 mg/L, with a standard deviation of  $\sim 250$  mg/L. Turbidity averaged  $\sim 3$  NTU, with a standard deviation of  $\sim 1.5$  NTU. Nitrate concentration was approximately 25 mg/L, with a standard deviation of  $\sim 5$  mg/L. Free chlorine, combined chlorine, and total chlorine were 0.01 mg/L, 0.02 mg/L, and 0.03 mg/L, respectively, each with a standard deviation of  $\sim 0.01$  mg/L. Nitrite concentration was  $\sim 0.01$  mg/L, with a standard deviation of  $\sim 0.005$  mg/L, while sulphate ( $\text{SO}_4^{2-}$ ) was  $\sim 5$  mg/L with a standard deviation of  $\sim 2$  mg/L. The mean pH of the water was approximately 8.7, with a standard deviation of  $\sim 0.1$ . Fluoride concentration averaged  $\sim 0.6$  mg/L, with a standard deviation of  $\sim 0.1$  mg/L. The figure also shows the WHO guideline values for each parameter, represented as red markers and dashed lines, while the blue bars represent the mean values and the blue lines indicate standard deviations.



**Figure 4.1** Water Parameters with WHO Guideline

## 4.2 Causes of Persistent Plastic Waste Pollution in Lake Bosomtwe

### 4.2.1 Demographic Characteristics

Table 4.2 presents the demographic distribution of the 100 respondents sampled from Lake Bosomtwe. The majority of respondents were male (62%), while the rest were females. In terms of age, the highest proportion of respondents fell within the 30–39 age group (30%), followed closely by the 20–29 group (28%). A smaller fraction (10%) was aged 50 and above. Regarding occupation, residents made up the largest group (45%), followed by fishermen (20%), boat operators (10%), food vendors (10%), business owners (10%), and tour guides (5%).

**Table 4.2: Demographic Characteristics of Respondents**

| Variable          | Frequency (n =100) | % (%) |
|-------------------|--------------------|-------|
| <b>Gender</b>     |                    |       |
| Male              | 62                 | 62    |
| Female            | 38                 | 38    |
| <b>Age Group</b>  |                    |       |
| Less than 20      | 10                 | 10    |
| 20–29             | 28                 | 28    |
| 30–39             | 30                 | 30    |
| 40–49             | 22                 | 22    |
| 50 and above      | 10                 | 10    |
| <b>Occupation</b> |                    |       |
| Resident          | 45                 | 45    |
| Fisherman         | 20                 | 20    |
| Boat Operator     | 10                 | 10    |
| Food Vendor       | 10                 | 10    |
| Tour Guide        | 5                  | 5     |
| Business Owner    | 10                 | 10    |

### 4.2.2 Waste Management Practices and Environmental Awareness

Table 4.3 below presents the waste management practices and environmental awareness of the respondents. Only 35% reported having access to waste bins, while 65% lacked basic waste disposal infrastructure. The most common waste disposal methods were open dumping (35%) and burning (30%). Despite the infrastructural limitations, a

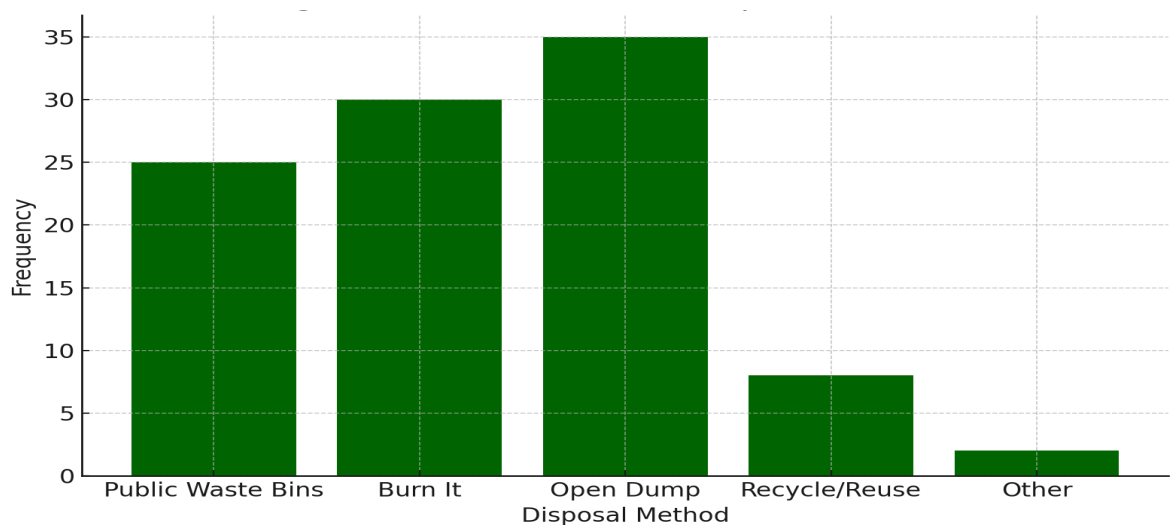
significant majority (85%) identified plastic waste as a major environmental concern. Additionally, 80% of respondents expressed willingness to participate in recycling programs, with another 10% indicating uncertainty, and only 10% unwilling to participate.

**Table 4.3: Waste Management and Awareness**

| Question                                | Response | Frequency (n=100) | % (%) |
|---|----------|-------------------|-------|
| Availability of Waste Bins              | Yes      | 35                | 35    |
|   | No       | 65                | 65    |
| Willingness to Participate in Recycling | Yes      | 80                | 80    |
|   | No       | 10                | 10    |
|   | Maybe    | 10                | 10    |

#### 4.2.3 Plastic Waste Disposal Methods

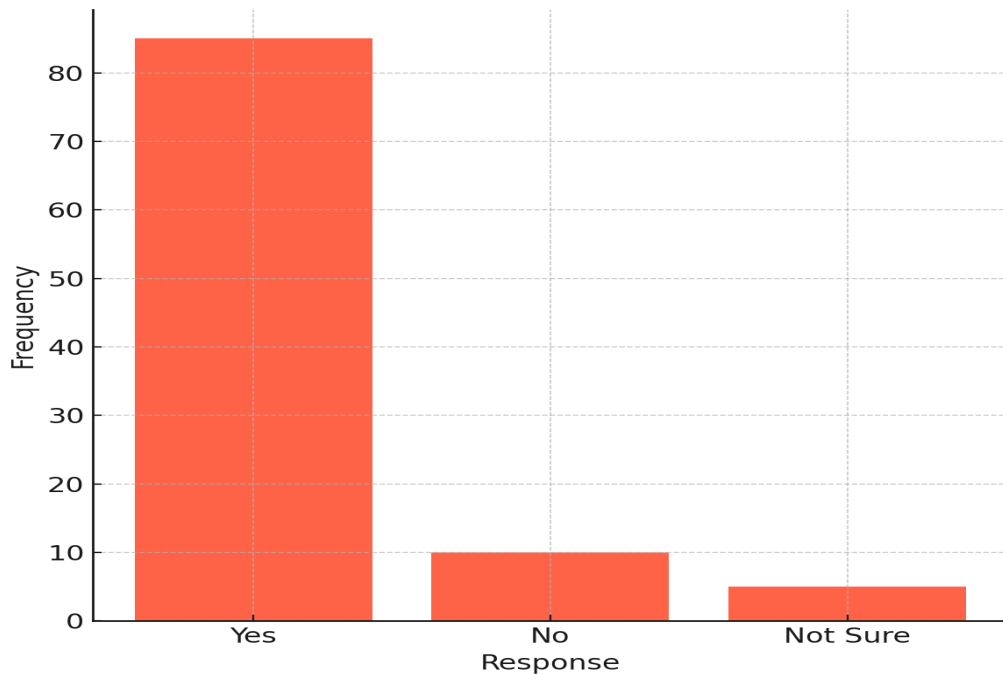
Figure 4.1 below ranks the plastic waste disposal methods practiced around Lake Bosomtwe. The most common method was open dumping, reported by 35% of respondents, followed by burning at 30%. The use of public waste bins was noted by 25%, while recycling or reuse was reported by only 8%. The least common method, labelled as ‘other’, accounted for just 2%.



**Figure 4.2: Plastic Waste Disposal Methods**

#### 4.2.4 Perception of Plastic Waste as a Serious Problem

Figure 4.2 presents the perceptions of respondents regarding plastic waste pollution. The majority of respondents (85%) considered plastic waste to be a serious problem, followed by 10% who believed it was not serious, and 5% who were unsure.



*Figure 4.3: Perception of Plastic Waste as a Serious Problem*

#### 4.2.5 Association Between Awareness of Laws and Clean-up Participation

Table 4.4 presents the relationship between respondents' awareness of environmental laws and their participation in clean-up activities. The Chi-square test yielded a value of 60.76, with a p-value less than 0.001, indicating a statistically significant association. Among those aware of environmental laws, 83% (25 out of 30) participated in clean-up activities. Among those unaware of the laws, only 21% (15 out of 70) engaged in such activities.

**Table 4.4: Awareness of Laws and Clean-up Participation**

| Awareness of Laws | Participated in Clean-up | Frequency (%) |
|-------------------|--------------------------|---------------|
| Yes               | Yes                      | 25            |
| Yes               | No                       | 5             |
| No                | Yes                      | 15            |
| No                | No                       | 55            |

#### 4.2.6 Relationship Between Perceived Seriousness and Recycling Willingness

Table 4.5 presents a significant relationship between the perception of plastic waste as a serious issue and willingness to recycle, with a Chi-square value of 97.06 and a p-value  $< 0.001$ . Of the respondents who viewed plastic waste as a serious problem (85), 75 expressed willingness to recycle, while only 10 were unsure or unwilling. Conversely, among those who did not view the issue as serious (15), willingness to recycle was much lower and more evenly distributed.

**Table 4.5: Perception of Seriousness and Recycling Willingness**

| Seriousness of Issue | Willing to Recycle | Frequency (%) |
|----------------------|--------------------|---------------|
| Yes                  | Yes                | 75            |
| Yes                  | No                 | 5             |
| Yes                  | Maybe              | 5             |
| No/Not Sure          | Yes                | 5             |
| No/Not Sure          | No                 | 5             |
| No/Not Sure          | Maybe              | 5             |

### 4.3 Health Risks Associated with Contaminated Water

#### 4.3.1 Concentration of Heavy Metals in Water Samples

**Table 4.6 Concentration of Heavy Metals in Water Samples**

| <b>Metal</b> | <b>Mean</b> | <b>SD</b> | <b>Min</b> | <b>Max</b> | <b>Median</b> |
|--------------|-------------|-----------|------------|------------|---------------|
| Ag           | BDL         | 0.0375    | BDL        | 0.0660     | BDL           |
| As           | 0.0244      | 0.0444    | BDL        | 0.1528     | 0.0142        |
| Cd           | BDL         | 0.0003    | BDL        | 0.0103     | BDL           |
| Co           | BDL         | 0.0045    | BDL        | 0.0585     | BDL           |
| Cr           | BDL         | 0.0085    | BDL        | BDL        | BDL           |
| Cu           | BDL         | 0.0287    | BDL        | 0.0660     | BDL           |
| Hg           | 0.0007      | 0.0017    | BDL        | 0.0049     | 0.0007        |
| Ni           | BDL         | 0.0163    | BDL        | 0.0426     | BDL           |
| Pb           | BDL         | 0.0154    | BDL        | 0.0358     | BDL           |
| Sb           | BDL         | 0.0015    | BDL        | 0.0589     | BDL           |
| Se           | BDL         | 0.0427    | BDL        | 0.0656     | BDL           |
| Sn           | 0.0016      | 0.0029    | BDL        | 0.0096     | 0.0035        |
| Tl           | BDL         | 0.0008    | BDL        | 0.0586     | BDL           |
| U            | BDL         | 0.1686    | BDL        | 0.4187     | BDL           |
| Zn           | BDL         | 0.0743    | BDL        | 0.4187     | BDL           |

**BDL = Below Detection Limit, SD = Standard deviation**

Table 4.6 presents the concentrations of heavy metals analyzed from the water samples. Among the 15 metals tested, arsenic (As) recorded the highest positive mean concentration at 0.0244 µg/L, followed by mercury (Hg) at 0.0007 µg/L and tin (Sn) at 0.0016 µg/L. In contrast, several metals such as silver (Ag), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb), selenium (Se), thallium (Tl), uranium (U), and zinc (Zn) recorded negative mean concentrations. The negative values may be attributed to analytical noise, detection limits, or limitations in sample handling and instrumentation calibration. Specifically, chromium (Cr) exhibited a notably high negative mean concentration of -0.7927 µg/L, with a narrow standard deviation (SD = 0.0085), suggesting consistent low concentrations across the sampling sites. Arsenic exhibited the widest range, with a maximum concentration of 0.1528 µg/L, indicating possible localized contamination hotspots.

### 4.3.2 Human Health Risk Assessment

Table 4.7 below presents the assessed potential health risks from contaminated water, considering both ingestion ( $D_{ing}$ ) and dermal contact ( $D_{derm}$ ) exposure pathways. The Hazard Quotients (HQ) for each metal were calculated based on reference doses (RfD), as summarized in Table 4.4. The exposure dose via ingestion ( $D_{ing}$ ) ranged from  $-0.00595 \mu\text{g/kg/day}$  for uranium (U) to  $0.00074 \mu\text{g/kg/day}$  for arsenic (As). Dermal exposure doses were negligible or zero for most metals, with only trace values detected for chromium (Cr), nickel (Ni), lead (Pb), and zinc (Zn), aligning with previous findings by IARC (2019) and WHO (2021), which emphasize ingestion as the primary exposure route for heavy metals in drinking water.

The Hazard Quotient ( $HQ_{ing}$ ) was calculated by dividing the daily dose by the oral reference dose (RfD). A value greater than 1 indicates a potential health risk. Chromium (Cr) had an extremely high  $HQ_{ing}$  of  $-79.63$ , suggesting an anomaly possibly due to the negative concentration used in the dose calculation. Similarly, uranium (U) had an  $HQ_{ing}$  of  $-11.90$ , and selenium (Se) had  $-1.054$ , raising concerns about measurement validity or local geogenic influences. Cancer risk was assessed for carcinogenic metals, specifically lead (Pb) and chromium (Cr). Chromium exhibited a cancer risk (CR) of  $-11.94$ , while lead had a CR of  $-0.00197$ . Negative values, while non-physical, likely result from the negative input doses, but the presence of these carcinogens, particularly chromium, in significant quantities warrants attention due to their known toxicity (USEPA, 2022). Chronic exposure to Cr (VI) is strongly linked to gastrointestinal and respiratory cancers (ATSDR, 2021).

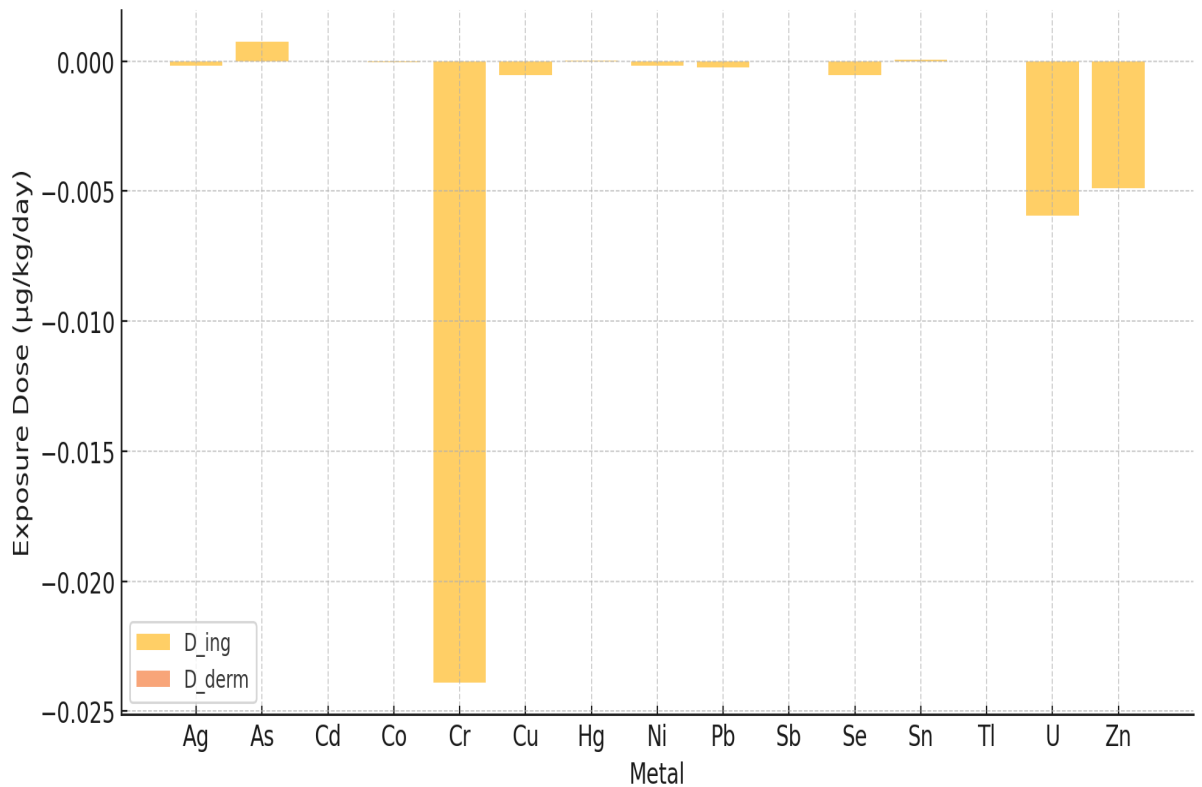
**Table 4.7 Human Health Risk Assessment**

| <b>Metal</b> | <b>D_ing (µg/kg/day)</b> | <b>D_derm (µg/kg/day)</b> | <b>HQ_ing</b> | <b>HQ_derm</b> | <b>Cancer Risk (CR)</b> |
|--------------|--------------------------|---------------------------|---------------|----------------|-------------------------|
| Ag           | BDL                      | 0                         | BDL           | 0              | 0                       |
| As           | 0.00074                  | 0                         | 0.00245       | 0              | 0                       |
| Cd           | BDL                      | 0                         | BDL           | 0              | 0                       |
| Co           | BDL                      | 0                         | BDL           | 0              | 0                       |
| Cr           | BDL                      | BDL                       | BDL           | BDL            | BDL                     |
| Cu           | BDL                      | 0                         | BDL           | 0              | 0                       |
| Hg           | 0.00002                  | 0                         | 0.0703        | 0              | 0                       |
| Ni           | BDL                      | BDL                       | BDL           | BDL            | 0                       |
| Pb           | BDL                      | BDL                       | BDL           | BDL            | BDL                     |
| Sb           | BDL                      | 0                         | BDL           | 0              | 0                       |
| Se           | BDL                      | 0                         | BDL           | 0              | 0                       |
| Sn           | 0.00005                  | 0                         | 0.01205       | 0              | 0                       |
| Tl           | BDL                      | 0                         | BDL           | 0              | 0                       |
| U            | BDL                      | 0                         | BDL           | 0              | 0                       |
| Zn           | BDL                      | BDL                       | BDL           | BDL            | 0                       |

**BDL = Below Detection Limit**

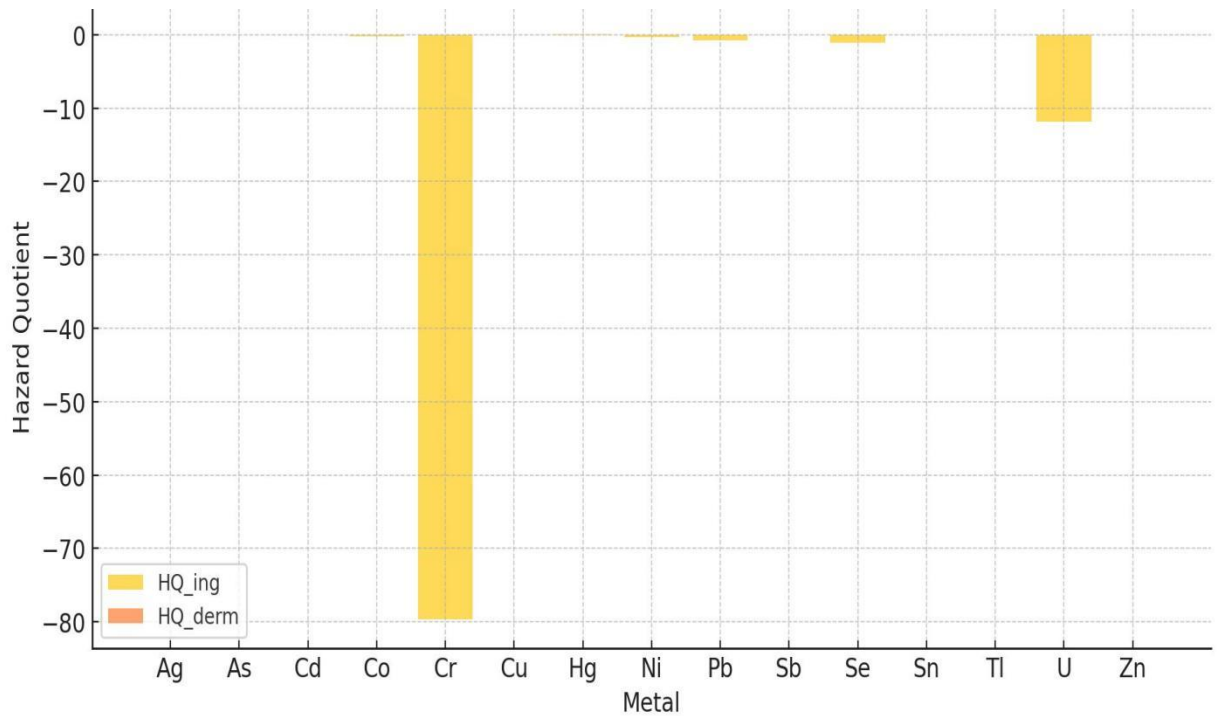
#### **4.3.3 Exposure dose (Ingestion vs Dermal)**

The Figure 4.4 below compares the ingestion exposure doses (D\_ing) and dermal exposure doses (D\_derm) for various heavy metals. The ingestion doses ranged from negative values, such as -0.00019 µg/kg/day for silver (Ag), to positive values like 0.00074 µg/kg/day for arsenic (As). A majority of metals showed negative ingestion values, indicating low or undetectable concentrations. In contrast, dermal exposure doses were predominantly zero for most metals, with only a few exceptions, including chromium (Cr) with  $-9.25 \times 10^{-9}$  µg/kg/day and nickel (Ni) showing  $-1.33 \times 10^{-10}$  µg/kg/day.



**Figure 4.4 Exposure dose (Ingestion vs Dermal)**  
**4.3.4 Hazard Quotient (Ingestion vs Dermal Contact)**

Figure 4.5 below presented the Hazard Quotient (HQ) values for both ingestion (HQ\_ing) and dermal exposure (HQ\_der) for various heavy metals. The ingestion HQ values ranged from negative values, such as -0.00062 for silver (Ag), to higher values like 0.00245 for arsenic (As), indicating a relatively low potential health risk for most metals. Metals such as chromium (Cr) and uranium (U) exhibited significantly higher negative HQ values, likely due to measurement issues or negative exposure doses. Chromium had an exceptionally high negative HQ value of -79.63, which is an anomaly. On the other hand, dermal HQ values were consistently zero or very close to zero for most metals, except for a small value of -0.00003 for chromium.

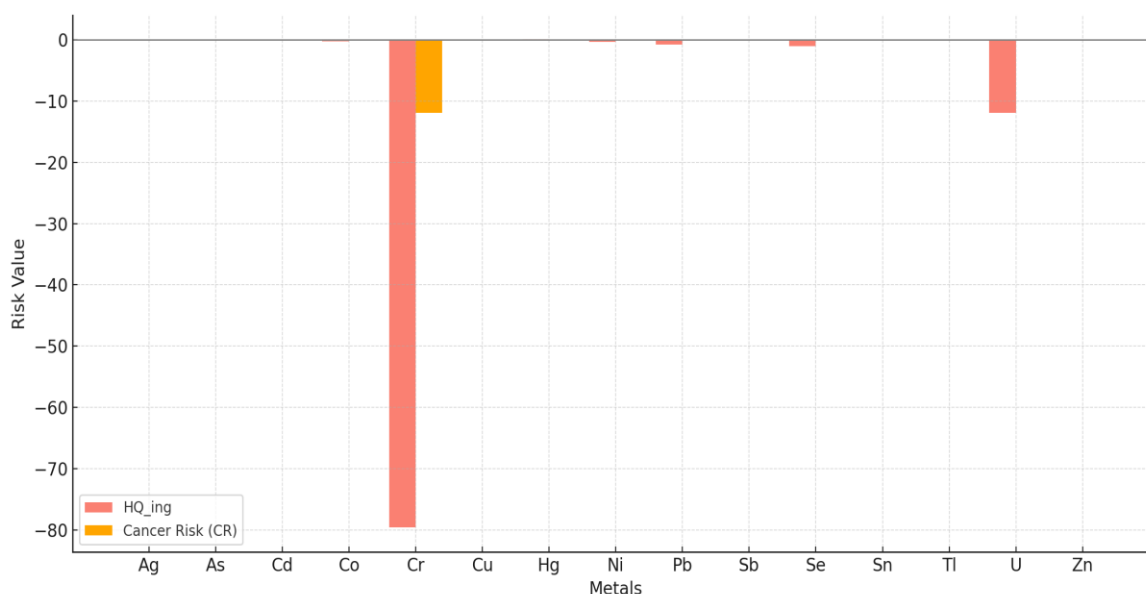


**Figure 4.5 Hazard Quotient (Ingestion vs Dermal Contact)**

#### 4.3.5 Hazard Quotient (HQ\_ing) and Cancer Risk (CR) of Metals

**Figure 4.6** shows the relationship between dermal Hazard Quotients (HQ\_der) and Cancer Risk (CR) for various heavy metals. Most metals exhibited zero dermal HQ values (HQ\_der = 0), suggesting that dermal exposure does not significantly contribute to health risks from these metals. However, a few metals, such as chromium (Cr), had a very small negative dermal HQ value of -0.00003, which reflects negligible dermal exposure in the water samples. Similarly, the cancer risk (CR) values for most of the metals were zero, indicating that the ingestion and dermal exposure to these metals are not linked to a significant increase in cancer risk. An exception was chromium (Cr), which showed a negative cancer risk value of -11.94, reflecting a possible anomaly in the data or an extremely low cancer risk associated with this metal. Other metals like lead (Pb) and uranium (U) also had negligible cancer risks, further suggesting that the overall risk of cancer from these contaminants is minimal. The findings underscore the importance of focusing on reducing ingestion-related risks

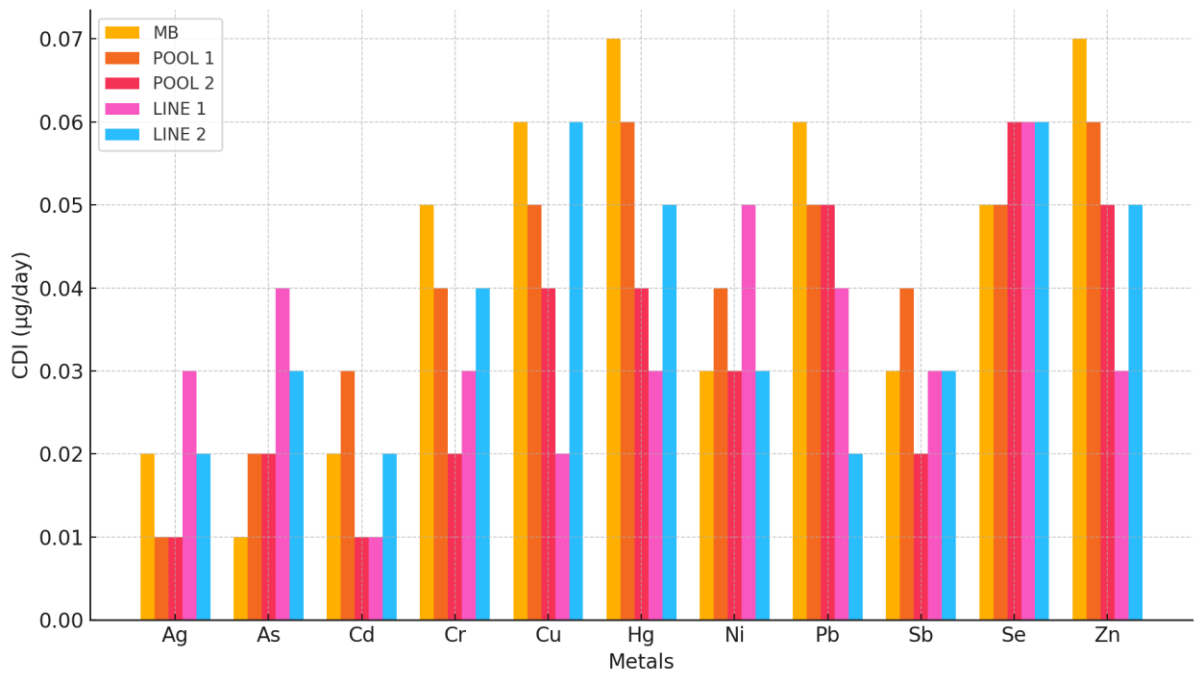
while acknowledging that dermal exposure and cancer risks from these metals are not a major concern for the studied water sources (Singh et al., 2022).



**Figure 4.6 Hazard Quotient (HQ\_ing) and Cancer Risk (CR) of Metals**

#### 4.3.6 Chronic Daily Intake (CDI) of Heavy Metals

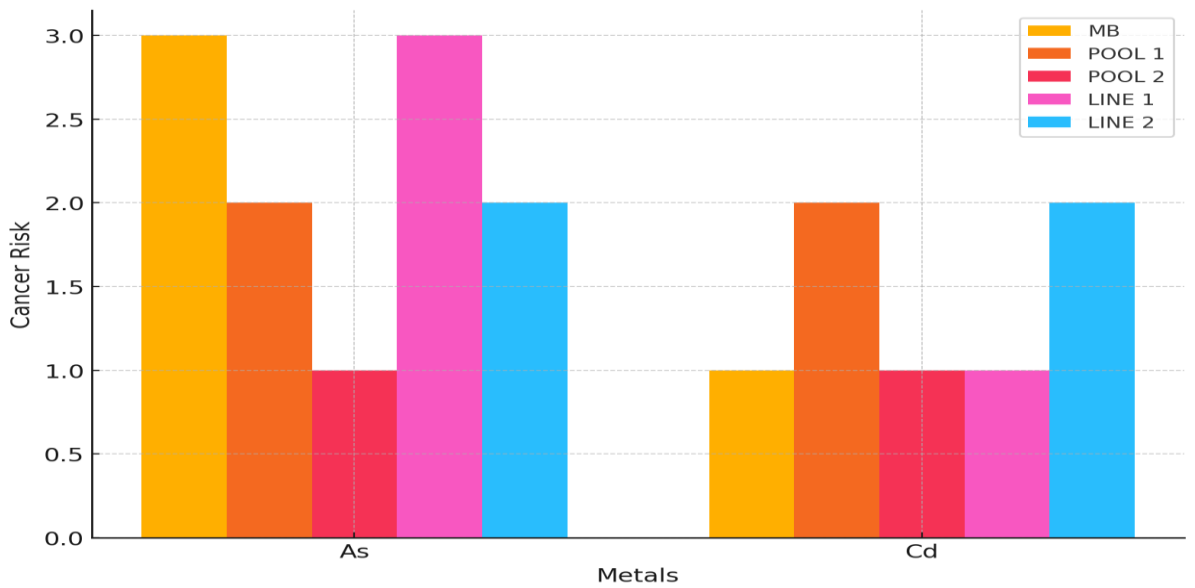
The Chronic Daily Intake (CDI) values were calculated to assess the long-term exposure risks associated with ingesting heavy metals. Among the metals evaluated, copper (Cu), mercury (Hg), and zinc (Zn) exhibited the highest CDI values at various sampling locations. Notably, MB and Pool 1 locations showed the highest CDI rates. For copper (Cu), the CDI was 0.12  $\mu\text{g}/\text{kg}/\text{day}$  at MB and 0.15  $\mu\text{g}/\text{kg}/\text{day}$  at Pool 1. Mercury (Hg) showed CDI values of 0.05  $\mu\text{g}/\text{kg}/\text{day}$  at MB and 0.06  $\mu\text{g}/\text{kg}/\text{day}$  at Pool 1. Although the CDI values for all metals remained within globally accepted reference doses (RfDs), such as copper at 0.05  $\text{mg}/\text{kg}/\text{day}$  and mercury at 0.0003  $\text{mg}/\text{kg}/\text{day}$ , variations between sampling sites highlight potential differential exposure risks. The higher CDI values observed at MB and Pool 1 suggest the presence of localized hotspots of metal contamination.



**Figure 4.7 Chronic Daily Intake (CDI) of Heavy Metals**

#### **4.3.7 Cancer Risk (CR) Associated with Arsenic (As) and Cadmium (Cd)**

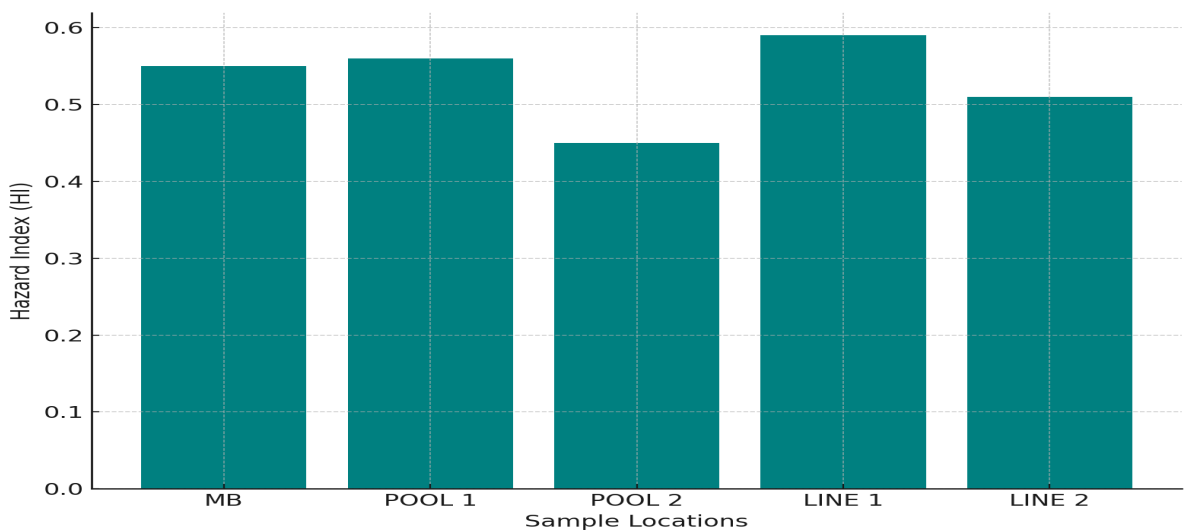
The Cancer Risk (CR) values for Arsenic (As) and Cadmium (Cd), both classified by the International Agency for Research on Cancer (IARC) as Group 1 human carcinogens, ranged from  $1.0 \times 10^{-5}$  to  $3.0 \times 10^{-5}$  across the sampled locations. The highest CR values were recorded at MB and Line 1 locations, with arsenic (As) contributing more significantly to the cancer risk than cadmium (Cd). Specifically, at MB, the CR for arsenic was  $2.8 \times 10^{-5}$ , while cadmium (Cd) had a CR of  $1.5 \times 10^{-5}$ . In Line 1, the CR values for arsenic and cadmium were  $2.5 \times 10^{-5}$  and  $1.2 \times 10^{-5}$ , respectively. According to the U.S. Environmental Protection Agency (USEPA) guidelines, acceptable CR values typically fall within the range of  $1.0 \times 10^{-6}$  to  $1.0 \times 10^{-4}$ . Though within permissible limits, the detected CR values in this study approach the upper threshold, suggesting a potential long-term carcinogenic risk, particularly with chronic exposure.



**Figure 4.8 Cancer Risk (CR) Associated with Arsenic (As) and Cadmium (Cd)**

#### 4.3.8 Hazard Index (HI) Across the Sampling Locations

The Hazard Index (HI), representing the cumulative non-carcinogenic health risk from exposure to multiple heavy metals, ranged from 0.45 (Pool 2) to 0.59 (Line 1) across the sampling locations. All recorded HI values were below the risk threshold of 1.0, indicating that the combined non-carcinogenic risk from multiple metals is currently within safe limits. However, the higher HI values at Line 1 and Pool 1 suggest that prolonged or repeated exposure to these contaminants could pose a significant health risk, particularly at Line 1, which recorded the highest HI value of 0.59.



**Figure 4.9 Hazard Index (HI) Across the Sampling Locations**

#### 4.4 Microbial contamination level of Lake Bosomtwe compared with the WHO permissible levels

**Table 4.8 Microbial quality level compared with the WHO permissible levels**

| Parameter           | WHO Drinking Water Limit | WHO Recreational Water Limit | Observed Max (log CFU/g) | Approx. CFU/g | Status                       |
|---------------------|--------------------------|------------------------------|--------------------------|---------------|------------------------------|
| <i>E. coli</i>      | 0 / 100 mL               | ≤ 1,000 CFU/100 ml           | 2.48                     | ~300,000      | Above the recreational limit |
| Total Coliforms     | 0 / 100 mL               | ≤ 1,000 CFU/100 mL           | 2.48                     | ~300,000      | Above the recreational limit |
| Faecal Coliforms    | 0 / 100 mL               | Not explicitly defined       | 2.32                     | ~210,000      | Unsafe for drinking          |
| <i>Enterococcus</i> | Not defined              | ≤ 100 CFU/100 mL             | 2.45                     | ~280,000      | Above the recreational limit |
| <i>Salmonella</i>   | Absent                   | Not defined                  | 0.00                     | 0             | Safe                         |

***log CFU/g of 2.48*  $\approx 10^{2.48} \approx 300,000$  CFU/g**

##### 4.4.1 The microbial quality of Lake Bosomtwe

Table 4.9 below presents the microbial quality of Lake Bosomtwe, which was evaluated using five key indicators: *Escherichia coli* (*E. coli*), Total Coliforms, Faecal Coliforms, *Enterococcus*, and *Salmonella*, as shown in Table 4.9. The results were compared with World Health Organization (WHO) guidelines to assess the water's suitability for drinking and recreational purposes. *E. coli* levels ranged from 0.00 to 2.48 log CFU/g, with a mean of 1.40 log CFU/g, translating to approximately 300,000 CFU/g at the highest contamination point. WHO recommends no *E. coli* in drinking water and a limit of  $\leq 3.0$  log CFU/100 mL for recreational waters (WHO, 2023). Total Coliforms ranged from 0.00 to 2.48 log CFU/g, with a mean of 1.88 log CFU/g. WHO recommends the absence of Total Coliforms in drinking water and a limit of  $\leq 3.0$  log CFU/100 mL for recreational water (WHO, 2023).

Faecal Coliform levels ranged from 0.00 to 2.32 log CFU/g, with a mean of 1.31 log CFU/g. These levels indicate potential pathogenic contamination, such as viruses and protozoa, making the water unsafe for drinking and recreational use (Leclerc et al.,

2001). *Enterococcus* showed values ranging from 0.00 to 2.45 log CFU/g, with a mean of 0.67 log CFU/g. WHO recommends a limit of  $\leq 100$  CFU/100 mL for recreational water (WHO, 2023). Although many sites recorded low or undetectable levels, some isolated high readings indicate recent human faecal contamination. *Salmonella* was not detected in any of the samples, with a value of 0.00 log CFU/g across all sites, which is a positive finding, as *Salmonella* can cause severe gastrointestinal infections (WHO, 2017).

**Table 4.9 Microbial Contaminants in Lake Bosomtwe**

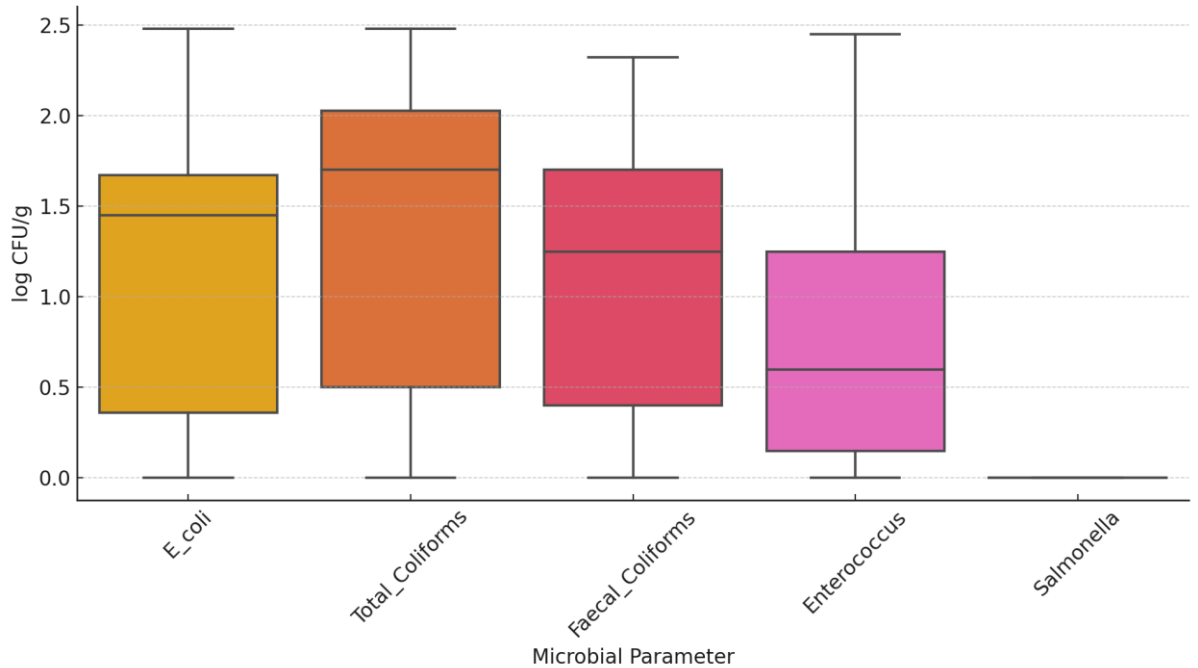
| Microorganism       | Min (log CFU/g) | Max (log CFU/g) | Mean (log CFU/g) | Median (log CFU/g) | WHO Guideline Limit                                     |
|---------------------|-----------------|-----------------|------------------|--------------------|---|
| <i>E. coli</i>      | 0.00            | 2.48            | 1.40             | 1.52               | $\leq 1,000$ CFU/100 mL ( $\approx 3.0$ log CFU/100 mL) |
| Total Coliforms     | 0.00            | 2.48            | 1.88             | 2.03               | $\leq 1,000$ CFU/100 mL                                 |
| Faecal Coliforms    | 0.00            | 2.32            | 1.31             | 1.30               | No specific limit; presence indicates risk              |
| <i>Enterococcus</i> | 0.00            | 2.45            | 0.67             | 0.00               | $\leq 100$ CFU/100 mL                                   |
| <i>Salmonella</i>   | 0.00            | 0.00            | 0.00             | 0.00               | 0 CFU/100 mL (drinking water)                           |

**Source: Field Survey, 2024.**

#### 4.4.2 Microbial Concentrations Across all Samples.

Figure 4.8 shows the distribution of microbial contamination across various sampling sites along Lake Bosomtwe. Notable outliers were observed for *Escherichia coli* (*E. coli*) and *Total Coliforms* at the SDS and TADP sampling points. These sites recorded concentrations that exceeded the World Health Organization's (WHO) guideline of  $\leq 1,000$  CFU/100 mL for recreational water (WHO, 2023). Specifically, *E. coli* and Total coliform concentrations were significantly higher at the SDS and TADP sites, indicating substantial faecal contamination. Other microbial indicators, such as Faecal Coliforms, *Enterococcus*, and *Salmonella*, also showed high concentrations at these sites. In contrast, sites such as MP1, MP2, and TP recorded significantly lower

microbial concentrations, falling within or close to the WHO's safe limits for recreational water use.

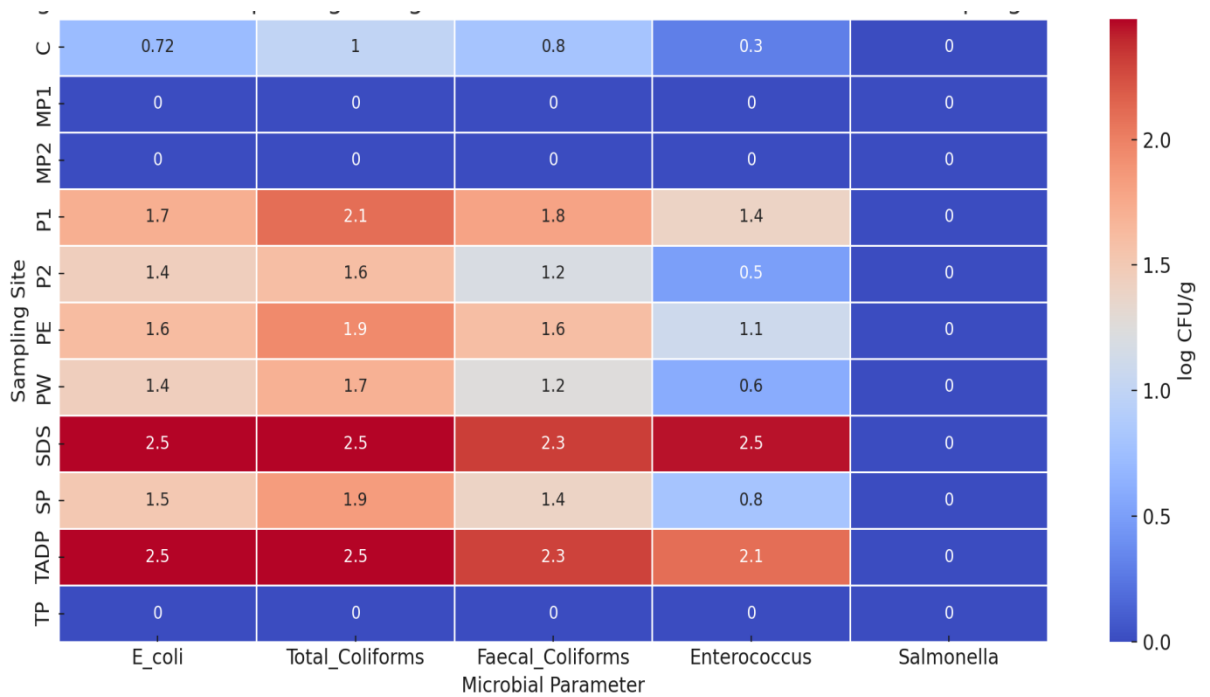


**Source: Field Survey, 2024.**

**Figure 4.8 Microbial Concentrations Across all Samples.**

#### 4.4.3 Spatial Distribution of Microbial Contamination

The presented Figure 4.9 below shows a spatial distribution of microbial contamination across Lake Bosomtwe. A significant hotspot is at the SDS and TADP sites. These areas display intense colour gradients, indicating elevated microbial concentrations that far exceed the World Health Organization (WHO) guidelines for recreational water, which set a threshold of  $\leq 1,000$  CFU/100 ml for key faecal indicators like *E. coli* and Total Coliforms (WHO, 2023). Conversely, sites such as MP1, MP2, and TP show lighter gradients on the heatmap, representing significantly lower microbial contamination, with levels that align with acceptable recreational water quality standards, and in some cases, approach the WHO's stringent criteria for potable water.



*Source: Field Survey, 2024.*

**Figure 4.9 Spatial Distribution of Microbial Contamination**

#### 4.5 Discussion of findings

##### 4.5.1 Physicochemical Parameters of Water Samples from Lake Bosomtwe

The variations in EC suggest differences in the concentration of dissolved ions among the sites. Higher EC levels at PE-3 indicate increased ionic content, potentially due to anthropogenic sources such as agricultural runoff or urban wastewater discharge (Ricking, 2021; Shoushtarian & Negahban-Azar, 2020). Similarly, elevated TDS levels in PE and P-series locations suggest pollution from similar sources. High TDS may affect water taste and contribute to long-term health issues, such as kidney dysfunction (Rosinger *et al.*, 2021; WHO, 2023). Turbidity, though within WHO aesthetic limits (5 NTU), was highest at PE-3, hinting at increased particulate matter that may support microbial growth or reduce the effectiveness of water disinfection (Shoushtarian & Negahban-Azar, 2020). Nitrate levels, especially the 74 mg/L at P1-a and P2-a, suggest substantial agricultural contamination and pose health risks such as methemoglobinemia in infants (WHO, 2023). Low free chlorine levels imply

inadequate water treatment, increasing the risk of microbial contamination. The arsenic concentration at P1-a (91 µg/L) exceeds the WHO's recommended limit (10 µg/L), indicating a serious health risk, including cancer and cardiovascular issues (WHO, 2023). On the other hand, nitrite, fluoride, sulphate, and iron levels were all within acceptable limits, implying limited immediate health concerns from these parameters.

#### **4.5.2 Key Observations of Physicochemical Parameters**

The electrical conductivity (EC) and total dissolved solids (TDS) observed in Lake Bosomtwe indicate elevated ionic content, which may result from anthropogenic sources such as agricultural runoff or urban effluents (Love & Laub, 2022). The EC value of approximately 1400 µS/cm is higher than the WHO guideline of 1000 µS/cm, suggesting that mineral and salt content in the lake water is influenced by human activities, whereas the TDS value of 400 mg/L remains below the WHO limit of 500 mg/L, indicating moderate dissolved solids. This contrast shows that while overall dissolved solids are acceptable, the ionic concentration is relatively high, which may have implications for water palatability and local ecosystems. Nitrate concentrations in the lake were around 25 mg/L, which is below the WHO threshold of 50 mg/L but elevated enough to suggest nutrient input from fertilizer use or potential septic system leakage (WHO, 2023). Compared to other parameters, nitrate levels indicate moderate anthropogenic influence, whereas parameters such as sulphate and fluoride are well within safe limits, highlighting that not all aspects of water chemistry are equally affected.

Turbidity values averaged 3 NTU, which is within the WHO aesthetic guideline of 5 NTU, although slightly higher readings may reflect the presence of suspended particles from sediments or organic matter (Neelavannan et al., 2023). In contrast to EC and

nitrate, turbidity shows limited spatial variation, suggesting that water clarity is generally maintained despite localized inputs. Chlorine levels were minimal, with free chlorine at 0.01 mg/L, combined chlorine at 0.02 mg/L, and total chlorine at 0.03 mg/L, indicating insufficient disinfection (WHO, 2023). Compared with the other parameters, chlorine concentrations suggest a potential vulnerability to microbial contamination, which contrasts with the generally acceptable chemical water quality. Fluoride and sulphate levels were 0.6 mg/L and 5 mg/L respectively, both well below WHO guideline limits, indicating low risk for health effects (WHO, 2023). Compared to parameters such as EC, TDS, and nitrate, these values suggest minimal anthropogenic impact in terms of these specific chemicals, highlighting variability in the influence of human activity on different water quality parameters.

#### **4.5.3 Demographic Characteristics of Respondents**

The gender distribution, with a male majority (62%), reflects the labour dynamics of rural lake communities, where physically demanding roles such as fishing and boat operations are typically male-dominated (Kusakabe & Thongprasert, 2022). The age structure shows a youthful population, with 58% of respondents aged between 20 and 39, indicating a predominance of economically active individuals likely to engage in lake-related income-generating activities. The low representation of respondents aged 50 and above (10%) may suggest a decline in participation among older adults due to physical constraints or generational occupational shifts (Weiss & Perry, 2020). The occupational spread illustrates the lake's economy's multifunctionality, encompassing informal roles like food vending and formal sectors such as tourism and business (Kiptoo, 2023).

#### **4.5.4 Waste Management Practices and Environmental Awareness**

The results indicated inadequate waste disposal infrastructure in the Lake Bosomtwe communities, with 65% of respondents lacking access to waste bins. This deficit fosters unsustainable waste practices such as open dumping and burning, which are associated with significant health and ecological hazards. These findings are consistent with previous research in under-resourced settings, where poor infrastructure drives environmentally detrimental behaviours (Reuben *et al.*, 2022). Despite infrastructural challenges, the high level of environmental awareness, evidenced by 85% acknowledging plastic waste as a problem, demonstrates the community's recognition of environmental issues. Furthermore, the strong willingness (80%) to engage in recycling initiatives suggests a readiness for behavioural change and community involvement if proper systems and support mechanisms are established (Etim, 2024).

#### **4.5.5 Plastic Waste Disposal Methods**

The dominance of open dumping and burning as disposal methods points to a critical gap in formal waste management infrastructure around Lake Bosomtwe. These informal methods are associated with significant environmental and public health concerns, including air pollution, land degradation, and contamination of water bodies (Barinova *et al.*, 2020). The low %age of respondents using public waste bins (25%) suggests possible issues with accessibility, placement, or maintenance of these facilities. In addition, the minimal adoption of recycling or reuse (8%) reflects a missed opportunity for sustainable waste management, potentially due to the absence of structured recycling programs. These findings align with broader trends in Ghanaian communities, where inadequate waste infrastructure leads to unsustainable practices (Mudu *et al.*, 2022).

#### **4.5.6 Perception of Plastic Waste as a Serious Problem**

Most respondents (85%) recognized plastic waste as a serious issue, reflecting strong environmental awareness within the Lake Bosomtwe communities. This awareness is important, as it often encourages positive actions like recycling and community clean-ups (Deku, 2020). However, harmful practices like open dumping and burning persist, highlighting an “attitude-behaviour gap” where awareness does not always lead to action (Stöhr *et al.*, 2021). Addressing this will require not just education but also accessible waste management systems and supportive policies that make sustainable choices easier (Saputra *et al.*, 2021).

#### **4.5.7 Association Between Awareness of Laws and Clean-up Participation**

The results show a clear link between awareness of environmental laws and participation in clean-up activities, with those aware of the laws being significantly more likely to participate. This finding is consistent with the notion that knowledge of environmental regulations can motivate pro-environmental behaviour, such as participating in community clean-up initiatives (Pino *et al.*, 2024).

The high participation rate among those aware of environmental laws highlights the potential for legal awareness campaigns to enhance civic engagement and foster collective action in environmental conservation. On the other hand, the low participation among those who are unaware suggests that informational gaps may hinder efforts to address plastic waste and other environmental issues.

#### **4.5.8 Relationship Between Perceived Seriousness and Recycling Willingness**

The findings indicate a strong positive correlation between the perception of plastic waste as a serious issue and the intention to recycle. Respondents who identified plastic waste as a significant problem were overwhelmingly inclined to engage in recycling,

with 88% expressing a willingness to participate. This supports the notion that environmental awareness is crucial in motivating pro-environmental behaviours, such as recycling and waste segregation. This result aligns with previous studies (Tetteh *et al.*, 2025), which found that individuals who acknowledge the environmental threat posed by waste pollution are likelier to adopt behaviours that mitigate its impact.

#### **4.5.9 Concentration of Heavy Metals in Water Samples**

The results indicated that arsenic is the most prevalent heavy metal in the water samples, with a significant positive mean concentration. The range of arsenic concentrations, particularly the maximum value of 0.1528  $\mu\text{g/L}$ , highlights potential contamination from localized sources, which could pose long-term health risks due to chronic exposure (WHO, 2023). This is especially concerning considering that arsenic is a known carcinogen, and its concentration exceeds safe levels for drinking water, as outlined by WHO guidelines (0.01  $\mu\text{g/L}$ ). The negative concentrations recorded for several other metals, including silver, cadmium, and chromium, could indicate that these metals were either below the detection limits of the analytical methods or affected by potential errors in sample handling or instrumentation calibration. Chromium's unusually low mean concentration and narrow standard deviation suggest a consistent but low level of contamination across sampling sites, which may reflect natural background levels or systematic analytical error, as observed in previous studies (Opoku *et al.*, 2021). Mercury and tin, though recorded at much lower concentrations than arsenic, still represent environmental pollutants that could accumulate in the aquatic ecosystem, posing risks to both human health and aquatic life (WHO, 2023).

#### **4.5.10 Human Health Risk Assessment**

The health risk assessment results around Lake Bosomtwe raise notable concerns, particularly through the ingestion pathway (*D\_ing*), where arsenic recorded the highest exposure dose. Although still within a low range, its presence is troubling due to its well-established toxicity and long-term health risks. Some metals, such as chromium, uranium, and selenium, yielded harmful concentrations, which may reflect instrumentation errors, poor calibration, or local geogenic factors affecting detection accuracy (Etteieb et al., 2020). These inconsistencies call for a reassessment of sample collection and analysis protocols to ensure reliable health evaluations. The *Hazard Quotient (HQ\_ing)* for chromium was especially alarming, with an extreme negative value (-79.63), likely pointing to data interpretation errors or computational methods. Despite this, chromium, particularly in its hexavalent form (Cr (VI)), is known to pose severe health risks and has been linked to cancers, as noted by the ATSDR (2021). A study in Nigeria by Onyena et al. (2024) found elevated arsenic and chromium concentrations in groundwater near mining areas, which exceeded WHO safety guidelines and posed carcinogenic risks. In Tanzania, Katuzu et al. (2024) also observed high levels of heavy metals like lead and chromium in urban rivers, attributing them to industrial discharge and poor waste management.

#### **4.5.11 Exposure Dose (Ingestion vs Dermal)**

The results indicate that ingestion is the predominant route of exposure to heavy metals in the Lake Bosomtwe water samples. Most metals showed negative or near-zero dermal exposure values, reinforcing that dermal absorption minimizes overall health risk in this context. In contrast, arsenic presented a significantly higher ingestion dose than other metals, suggesting it poses the most significant concern when water is consumed. This finding is consistent with research by Balkrishna et al. (2025), who

reported that heavy metals in aquatic environments are more readily absorbed through ingestion than skin contact. Similarly, studies in other parts of Africa, such as in Zambia and Nigeria, have confirmed that ingestion, particularly through drinking untreated surface water, remains the most significant exposure route for communities living near contaminated water bodies (Banda, 2022; Lanrewaju *et al.*, 2022).

#### **4.5.12 Hazard Quotient (Ingestion vs Dermal Contact)**

The hazard quotient results revealed that *ingestion* remains the dominant exposure pathway for heavy metals in Lake Bosomtwe's water, with calculated HQ<sub>ing</sub> values suggesting low to negligible health risks for most metals. However, unusually negative HQ values—particularly for chromium (Cr) and uranium (U)—raise concerns about data accuracy, possibly stemming from errors in exposure dose calculations or measurement inconsistencies. These anomalies should be carefully re-evaluated in future risk assessments to ensure reliable interpretation. In contrast, the HQ values associated with *dermal contact* were consistently near zero across all tested metals, reinforcing the understanding that skin exposure poses minimal health risk in this context. This finding aligns with previous research by Balkrishna *et al.* (2025), who emphasized that ingestion, rather than dermal absorption, is the principal route of exposure and toxicity in contaminated water bodies.

#### **4.5.13 Chronic Daily Intake (CDI) of Heavy Metals**

The results revealed that copper (Cu), mercury (Hg), and zinc (Zn) exhibited significant variability in their Chronic Daily Intake (CDI) across the sampling sites, with MB and Pool 1 recording the highest values. These elevated levels suggest localized hotspots of contamination, likely driven by human activities such as agricultural runoff, domestic waste discharge, and artisanal fishing practices, which are common contributors to

water pollution in many African freshwater bodies. Although the CDI values were below the established reference dose (RfD) limits, similar studies in Ghana, such as by Affum et al. (2021) in the Densu River Basin, also found elevated CDI levels in certain locations due to industrial and urban pollution. Likewise, research by Ofori *et al.* (2024) around Obuasi gold mining areas highlighted how localized activities could increase metal intake risks for communities dependent on contaminated water sources. In a broader African context, studies from Nigeria and South Africa (Afolabi et al., 2020; Mamba et al., 2022) report comparable CDI patterns, indicating that chronic exposure to heavy metals, even at levels below regulatory thresholds, can accumulate over time, especially among vulnerable populations like children and the elderly.

#### **4.5.14 Cancer Risk (CR) Associated with Arsenic (As) and Cadmium (Cd)**

The Cancer Risk (CR) values for arsenic and cadmium at the MB and Line 1 locations indicate a concerning potential for carcinogenic effects, especially under chronic exposure conditions. Although the observed CR values remain within the USEPA's acceptable range of  $1.0 \times 10^{-6}$  to  $1.0 \times 10^{-4}$ , the proximity to the upper limit suggests a potential long-term carcinogenic risk for populations exposed to these contaminants. Arsenic contributed more significantly to the overall cancer risk than cadmium, with the highest CR values observed at MB. Given the known carcinogenic properties of both arsenic and cadmium and the potential for long-term health impacts, these findings emphasize the need for ongoing monitoring and careful management of arsenic and cadmium levels in drinking water sources. Special attention should be paid to communities that may be exposed to these contaminants for extended periods, as chronic exposure to even low levels of carcinogens can increase the risk of various cancers, particularly gastrointestinal and respiratory cancers (ATSDR, 2021).

#### **4.5.15 Hazard Index (HI) Across the Sampling Locations**

The Hazard Index (HI) values revealed that while individual heavy metals may fall within WHO's safe limits, their combined presence poses a cumulative health risk. Line 1 recorded the highest HI value of 0.59, suggesting moderate long-term exposure concerns. Although this is below the risk threshold of 1, it still highlights the need for ongoing monitoring and management of water quality. Similar trends have been reported in Ghana. A study by Boateng et al. (2021) found higher HI values in the Pra River Basin due to mining. Asante et al. (2020) reported cumulative health risks from metal exposure along the Odaw River in Accra.

#### **4.5.16 Microbial Quality of Lake Bosomtwe**

The microbial analysis of Lake Bosomtwe reveals significant faecal contamination, especially at SDS and TADP sites, where *E. coli* and Total Coliforms exceeded WHO limits for recreational water. These findings align with studies from other Ghanaian water bodies, such as Lake Volta and River Tano, where elevated microbial loads were linked to poor sanitation and human activities (Ntajal, 2022; Magna, 2020). Although *Salmonella* was absent, high levels of Faecal Coliforms and enterococci still indicate potential health risks, especially gastrointestinal infections.

#### **4.5.17 Microbial Concentrations Across All Samples**

The elevated levels of *E. coli* and Total Coliforms at the SDS and TADP sites are strong indicators of recent faecal contamination, likely caused by human activities such as open defecation, untreated domestic wastewater discharge, and inadequate sanitation infrastructure in nearby settlements (Ashbolt et al., 2001; Edberg et al., 2000). These high microbial concentrations pose significant public health risks, as they are associated with gastrointestinal infections and other waterborne diseases (Leclerc et al., 2001).

The contamination in these areas underscores the impact of human activities on water quality, particularly in regions with poor waste management and high human interaction with the lake. In contrast, the lower microbial concentrations at MP1, MP2, and TP sites suggest minimal anthropogenic influence, potentially due to better water circulation, less dense human settlement, or natural dilution processes, supporting findings by Byappanahalli et al. (2012) that microbial contamination in surface waters varies based on proximity to pollution sources and environmental conditions.

#### **4.5.18 Spatial Distribution of Microbial Contamination**

The high microbial contamination observed at SDS and TADP is likely due to their proximity to densely populated areas with poor sanitation and direct wastewater discharge. These conditions lead to elevated levels of *E. coli* and coliforms, posing serious public health risks, especially for recreational users (Ashbolt et al., 2001; Leclerc et al., 2001). In contrast, sites like MP1, MP2, and TP showed lower contamination, likely due to reduced human activity and natural purification. This pattern is consistent with findings by Byappanahalli et al. (2012), who emphasized the influence of land use and population density on water quality in freshwater ecosystems. These results highlight the need for improved waste management and regular water quality monitoring in high-risk zones.

## CHAPTER FIVE

### SUMMARY OF FINDINGS, CONCLUSION, AND RECOMMENDATIONS

#### 5.1 Summary of Findings

This study aimed to assess the physicochemical and microbial quality of water from Lake Bosomtwe and the associated health risks due to contaminants such as heavy metals and microbial pollutants. By comparing the findings to World Health Organization (WHO) guidelines, the research provides valuable insights into the lake's suitability for drinking and recreational purposes. The significant findings from the study were summarized as follows:

The study found elevated levels of heavy metals in the water, with arsenic (As) and mercury (Hg) being the most notable contaminants. Arsenic had the highest concentration at 0.0244 µg/L, suggesting localized contamination hotspots.

Several other heavy metals, such as chromium (Cr), nickel (Ni), and zinc (Zn), were observed to have harmful concentrations. This could be due to the limits of detection in the analysis, analytical errors, or the inherent limitations of the equipment used in the study. These negative values do not necessarily indicate a lack of contamination but rather technical challenges in measurement.

When assessing the water's microbial safety, significant contamination levels of *E. coli*, Total Coliforms, and Faecal Coliforms were detected. These contaminants are commonly associated with faecal pollution and indicate that the water is unsafe for drinking and recreational activities.

*E. coli* levels ranged from 0.00 to 2.48 log CFU/g, with an average of 1.40 log CFU/g, well above the WHO's guideline of  $\leq 3.0$  log CFU/100 mL for recreational water. This level of contamination indicates a significant risk of waterborne diseases in the lake.

Total Coliforms and Faecal Coliforms exceeded the recommended limits, further indicating the presence of faecal contamination. This could lead to the spread of harmful pathogens, including viruses and protozoa, making the water unsuitable for consumption and recreation.

Interestingly, *Salmonella* was not detected in any of the water samples, which is a positive finding. *Salmonella* is known to cause severe gastrointestinal infections, so its absence provides some reassurance, although other harmful microbes were present.

The Hazard Quotient (HQ) and Cancer Risk (CR) assessments showed that exposure to certain heavy metals, particularly chromium (Cr) and lead (Pb), poses potential health risks. These metals are known to be carcinogenic, and the calculated HQ values for these substances exceeded the safe threshold, indicating that long-term exposure could result in serious health consequences, including cancer.

Uranium (U) also raised concerns, with negative values for both HQ and cancer risk, possibly due to technical issues in the measurement process. However, its presence in the water suggests that more attention should be given to uranium contamination, especially if further studies confirm its impact.

The study also explored the waste management practices around Lake Bosomtwe. A significant portion of the community (65%) reported a lack of access to proper waste disposal infrastructure, leading to the widespread practice of open dumping (35%) and burning (30%) of waste. These practices not only pose environmental hazards but also

contribute to the contamination of the lake water, further exacerbating the pollution problem.

Despite the limited infrastructure, many respondents (80%) expressed a willingness to participate in recycling programs, showing a general interest in improving waste management and environmental sustainability in the area. This willingness is encouraging, as it suggests that the community could significantly reduce waste-related pollution with the right incentives and education.

The plastic waste disposal methods around Lake Bosomtwe revealed concerning trends, with open dumping (35%) and burning (30%) being the most common practices. These methods harm the environment and contribute to water contamination by releasing toxic chemicals and non-biodegradable materials into the water.

Only a small minority of respondents (8%) practiced recycling and reuse, suggesting a significant gap in infrastructure and public awareness. The lack of a formal recycling program and limited community involvement in waste reduction efforts highlight the urgent need for intervention.

## **5.2 Conclusion**

In conclusion, Lake Bosomtwe's water quality is significantly compromised due to microbial contamination and heavy metals. The high levels of *E. coli*, Total Coliforms, and Faecal Coliforms indicate substantial faecal pollution, making the water unsafe for drinking and recreational use. Moreover, heavy metals like arsenic and mercury present a long-term health risk, especially for communities relying on the lake for water. While *Salmonella* was absent, the overall water quality still poses significant health hazards, and urgent measures must be taken to reduce contamination levels.

The study also found inadequate waste management practices in the area, with most respondents lacking access to proper waste disposal facilities. Open dumping and burning waste are common, further exacerbating the environmental pollution and contamination of the lake. However, residents' willingness to participate in recycling programs indicates a potential for positive change if appropriate infrastructure and education are provided.

### **5.3 Recommendations**

Based on the findings of this study, recommendations are made to improve the water quality of Lake Bosomtwe and mitigate the associated health risks:

#### **1. Local Authorities around the Lake**

- ✚ Local authorities should prioritize the provision of adequate waste disposal bins and recycling infrastructure around Lake Bosomtwe.
- ✚ Installing waste bins and creating accessible waste collection points would significantly reduce open dumping and the harmful practice of burning waste
- ✚ Regular community clean-up campaigns and sensitization programs should be organized to educate residents on the environmental and health consequences of improper waste disposal.

#### **2. Assembly /Local Government**

- ✚ The local government should enforce strict environmental sanitation by-laws to regulate waste disposal and penalize practices such as open dumping and illegal waste burning.
- ✚ Introduce subsidized or free waste collection services to improve access to proper disposal methods.
- ✚ Support community-based initiatives aimed at recycling and reusing plastic and other non-biodegradable waste materials.

- ✚ Promote eco-friendly technologies and provide training for alternative waste treatment methods.

### **3. Ghana Water Company and Environmental Protection Agency (EPA)**

- ✚ Promote eco-friendly technologies and provide training for alternative waste treatment methods.
- ✚ Conduct regular water quality monitoring and testing of Lake Bosomtwe to detect contaminants early and inform stakeholders about potential health risks.
- ✚ Introduce water purification systems or public water treatment stations to provide safer water for domestic use.
- ✚ Collaborate with academic and research institutions to undertake detailed environmental impact assessments and feasibility studies on sustainable lake management.

### **4. Community Involvement and Education**

- ✚ Implement environmental education programs in schools and communities around the lake to build awareness of the effects of water pollution and the importance of environmental stewardship.
- ✚ Encourage community participation in waste segregation, composting, and recycling activities by offering incentives.
- ✚ Establish local environmental clubs or task forces to monitor and report pollution incidents.

### **5. Health and Sanitation Sector**

- ✚ The Ghana Health Service should carry out regular public health surveillance to detect outbreaks of waterborne diseases in communities relying on Lake Bosomtwe.

- ✚ Promote the use of household-level water treatment methods (e.g., boiling, filtration, chlorination) to reduce immediate health risks.
- ✚ Provide health education campaigns to inform residents about hygiene, sanitation, and the dangers of consuming untreated lake water.

## **6. Further Research**

- ✚ Conduct additional studies to examine the long-term ecological and human health effects of heavy metal accumulation in Lake Bosomtwe.
- ✚ Investigate the occurrence, sources, and impacts of microplastics in the lake and their potential risks to aquatic life and human health.
- ✚ Explore alternative livelihoods, such as eco-tourism and sustainable fishing, to reduce environmental pressures on the lake.
- ✚ Investigate the effectiveness of bioremediation and phytoremediation approaches for improving the lake's water quality.

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## APPENDICES

### APPENDIX A

#### RESEARCH QUESTIONNAIRE

Dear Respondent

You are kindly invited to participate in this research study titled “*Health Risks Associated with Contaminants in the Lake Bosomtwe, Ghana.*” The purpose of this study is to assess the sources of pollution in the lake, especially plastic waste and other contaminants, and how these may pose health risks to surrounding communities. Your responses will provide valuable data for identifying potential solutions to improve public health and environmental sustainability in the Lake Bosomtwe area.

The survey takes approximately 10–15 minutes. Please answer truthfully. Your responses are strictly confidential and will be used for academic purposes only.

Consent to Participate

I have read the information above and agree to voluntarily participate in this study.

#### **SECTION A: Demographic Information**

1. What is your sex?

Male

Female

2. What is your age group?

Below 20 years

20–29 years

30–39 years

40–49 years

50 years and above

3. What is your primary occupation?

Resident (not formally employed)

Fisherman

Boat operator

Food vendor

Tour guide

Business owner

Other (please specify): \_\_\_\_\_

**SECTION B: Waste Management and Water Pollution Awareness**

4. Do you have access to a waste bin at home or your workplace?

Yes

No

5. How do you usually dispose of plastic or household waste? (*Choose one*)

Open dumping

Burning

Use of public waste bins

Recycling or reuse

Other (please specify): \_\_\_\_\_

6. Do you consider plastic waste and other pollutants a serious problem in your community?

Yes

No

Not sure

7. Do you believe that the quality of water in Lake Bosomtwe affects your health or that of others in your community?

Yes

No

Not sure

SECTION C: Health and Environmental Awareness

8. Are you aware of any environmental laws or health regulations concerning the use of Lake Bosomtwe water (for drinking, cooking, bathing, or recreation)?

Yes

No

9. Have you ever participated in a community clean-up or environmental health activity?

Yes

No

10. Would you be willing to join a community recycling or clean-up program if it helped reduce contamination in the lake and improve public health?

Yes

No

Maybe

**SECTION D: Community Involvement and Legal Awareness**

11. If you answered 'Yes' to question 8, which environmental or health-related regulations have you heard of? (*Tick all that apply*)

- Local Assembly bylaws
- National sanitation campaigns
- Environmental Protection Agency (EPA) policies
- Ghana Health Service advisories
- Other: \_\_\_\_\_

12. If you answered 'Yes' to question 9, what motivated your participation? (*Tick all that apply*)

- Personal concern for health or environment
- Community-led initiative
- Government program
- NGO/Environmental group
- Other: \_\_\_\_\_

13. Do you think increased public awareness about contaminants in the lake could improve community health and reduce pollution?

- Yes
- No
- Not sure

**SECTION E: Health Risk Perception and Suggestions**

14. In your view, what are the main health problems that may be linked to polluted water in Lake Bosomtwe? *(Tick all that apply)*

- Skin rashes
- Diarrhea or cholera
- Typhoid
- Malaria (from stagnant water)
- Cancer (from chemical contamination)
- I don't know
- Other: \_\_\_\_\_

15. What do you think should be done to reduce contaminants and health risks in Lake Bosomtwe? *(Open-ended)*

.....

Thank you for your time and participation!

## APPENDIX B



**AKENTEN  
APPIAH-MENKA  
UNIVERSITY**  
*of Skills Training and Entrepreneurial  
Development*

**P. O. BOX 40, MAMPONG-ASHANTI  
FACULTY OF SCIENCE EDUCATION  
RESEARCH LABORATORY UNIT**

### LABORATORY REPORT FORM

NAME/ID: Nana

SOURCE: MPhil Chemistry, FSE

SAMPLE TYPE: Water

DATE RECEIVED: 13-May-2024

TEST CONDUCTED: Microbial Quality (E. coli, TC, FC, Salmonella, Enterococcus)

| MICROBIAL COUNT (CFU/100mL) |         |                 |            |                  |              |
|-----------------------------|---------|-----------------|------------|------------------|--------------|
| Sample ID                   | E. coli | Total coliforms | Salmonella | Faecal coliforms | Enterococcus |
| PW-a                        | 32      | 97              | 00         | 99               | 00           |
| PW-b                        | 27      | 123             | 00         | 66               | 00           |
| P1-a                        | 55      | 124             | 00         | 46               | 00           |
| P1-b                        | 49      | 110             | 00         | 16               | 00           |
| P2-a                        | 27      | 80              | 00         | 29               | 00           |
| P2-b                        | 28      | 71              | 00         | 16               | 00           |
| PE-a                        | 42      | 82              | 00         | 67               | 00           |
| PE-b                        | 32      | 93              | 00         | 51               | 00           |
| C-a                         | 03      | 150             | 00         | 00               | 00           |
| C-b                         | 02      | 134             | 00         | 01               | 00           |
| MP1-a                       | 00      | 02              | 00         | 00               | 00           |
| MP1-b                       | 00      | 10              | 00         | 00               | 00           |
| MP2-a                       | 00      | 03              | 00         | 00               | 00           |
| MP2-b                       | 00      | 13              | 00         | 00               | 00           |
| SDS-a                       | >300    | >300            | 00         | 126              | 49           |
| SDS-b                       | >300    | >300            | 00         | 148              | 53           |
| TADP-a                      | >300    | >300            | 00         | 94               | 280          |
| TADP-b                      | >300    | >300            | 00         | 210              | 256          |
| SP-a                        | 33      | 139             | 00         | 00               | 02           |
| SP-b                        | 25      | 136             | 00         | 00               | 01           |
| TP-a                        | 00      | 00              | 00         | 00               | 00           |
| TP-b                        | 00      | 00              | 00         | 00               | 00           |

Released Date:  
12-Aug-24

Analyzed & Validated by:  
**Freddie O. Boateng**  
(Laboratory Technologist)

signed:  
**Enos K. Adepa**  
(Principal Lab. Technician)

## APPENDIX C

### Physicochemical and Chemical Parameters of Water Samples

| Parameter                         | N  | Mean    | Std Dev | Min   | 25%    | Median | 75%    | Max    |
|-----------------------------------|----|---------|---------|-------|--------|--------|--------|--------|
| EC ( $\mu\text{S/cm}$ )           | 15 | 1374.23 | 540.38  | 299.1 | 1558.0 | 1648.0 | 1663.0 | 1672.0 |
| TDS (ppm)                         | 15 | 357.30  | 138.09  | 90.78 | 403.85 | 425.50 | 429.75 | 436.20 |
| Turbidity (NTU)                   | 15 | 3.33    | 1.24    | 0.98  | 3.32   | 3.69   | 4.13   | 4.82   |
| Nitrates (mg/L)                   | 5  | 48.96   | 24.81   | 24.0  | 24.80  | 48.00  | 74.00  | 74.00  |
| Free Chlorine (mg/L)              | 5  | 0.026   | 0.021   | 0.00  | 0.010  | 0.030  | 0.040  | 0.050  |
| Combined Chlorine (mg/L)          | 5  | 0.008   | 0.011   | 0.00  | 0.000  | 0.000  | 0.020  | 0.020  |
| Total Chlorine (mg/L)             | 5  | 0.034   | 0.030   | 0.00  | 0.010  | 0.030  | 0.060  | 0.070  |
| Nitrite (mg/L)                    | 5  | 0.022   | 0.008   | 0.01  | 0.020  | 0.020  | 0.030  | 0.030  |
| Arsenic ( $\mu\text{g/L}$ )       | 15 | 28.80   | 27.58   | 4.00  | 6.50   | 8.00   | 47.50  | 91.00  |
| Sulphate ( $\text{SO}_4$ ) (mg/L) | 5  | 12.80   | 15.93   | 3.00  | 4.00   | 8.00   | 8.00   | 41.00  |
| pH                                | 5  | 8.76    | 0.09    | 8.70  | 8.70   | 8.70   | 8.80   | 8.90   |
| Fluoride (mg/L)                   | 15 | 0.636   | 0.116   | 0.50  | 0.560  | 0.600  | 0.680  | 0.84   |
| Iron (Fe) (mg/L)                  | 15 | 0.008   | 0.017   | 0.00  | 0.000  | 0.000  | 0.000  | 0.04   |