UNVERSITY OF EDUCATION, WINNEBA

MAMPONG - ASHANTI

HUMAN HEALTH RISK ASSESSMENT FROM EXPOSURE TO MICROBIAL AND CHEMICAL CONTAMINANTS IN GROUNDWATER SOURCES OCCURRING IN TAMALE METROPOLIS, NORTHERN REGION

BY

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MASTER OF PHILOSOPHY IN ENVIRONMENT AND OCCUPATIONAL HEALTH EDUCATION

OCTOBER, 2023

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A THESIS IN THE DEPARTMENT OF PUBLIC HEALTH EDUCATION OF THE FACULTY OF ENVIRONMENT AND PUBLIC EDUCATION, SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF PHILOSOPHY (ENVIRONMENT AND OCCUPATIONAL HEALTH EDUCATION) IN THE UNIVERSITY OF EDUCATION, WINNEBA

OCTOBER, 2023

DECLARATION

STUDENTS' DECLARATION

I, Emmanuel Obeng Bekoe, declare that this thesis, with the exception of quotations and references contained in published works which have all been identified and duly acknowledged, is entirely my own original work, and it has not been submitted, either in part or whole, for another degree elsewhere.

EMMANUEL OBENG BEKOE

SIGNATURE ………………………………

DATE……………………….……………

SUPERVISORS' DECLARATION

We hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for the supervision of a dissertation as laid down by the University of Education, Winneba.

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ACKNOWLEDGEMENT

My sincere thanks go to Almighty God for making this project a success. I would like to appreciate the constructive criticisms, corrections, suggestions and cooperation of my academic supervisors; Dr. Daniel Hayford, Dr. Dennis Dekugmen Yar, and all other staff of the department and faculty. I am grateful for their input into this work.

My profound gratitude also goes to my wife, Mrs. Irene Obeng Bekoe and siblings notably Ms. Stella Asiama, Mrs. Millicent Osei-Anim, Mr. William Bekoe and Mrs. Juanita Asamoah, whose encouragement and goodwill messages kept me going throughout this research work.

Last but not the least, special thanks go to Dr. Emmanuel Obeng Bekoe, Professor Mike Osei Atweneboana, Dr. Alexander Tetteh Nuer, Mr. Gerard Quarcoo, Mr. Hubbert Kyeremeh, and Richard Amoatey who have always been there to contribute to my growth and development as a student of research and whose philosophies will always be there to guide me in my academic pursuits.

DEDICATION

I dedicate this piece of work to the Almighty God for his endless mercies and my dear parents, Rev. Wilson and Mrs. Doris Asiama Bekoe.

TABLE OF CONTENTS

DECLARATION .... **i**
DEDICATION .... **iii**
ACKNOWLEDGEMENT .... **ii**
LIST OF TABLES .... **ix**
LIST OF FIGURES .... **x**
LIST OF PLATE .... **xi**
ABSTRACT .... **xii**

CHAPTER ONE **1**
INTRODUCTION **1**
1.1 Background 1
1.2 Problem Statement 3
1.3 The rationale of the study/Justification 4
1.4 Hypothesis 5
1.5 Research Questions 5
1.6 Objectives 5
1.6.1 General Objective 5
1.6.2 Specific Objectives 6
1.7 Scope and Limitation 6
1.8 Organisation of the Thesis 6

CHAPTER TWO **8**
LITERATURE REVIEW **8**
2.1 Groundwater sources, occurrence and distribution 8
2.2 Groundwater abstraction and utilisation 9
2.3 Regulations and water rights 11
2.4 Water and Sanitation 12
2.5 Water distribution in Northern Ghana 14
2.6 State of water quality 15
2.7 Ghana’s water policy 18
2.8 Water stress challenge 21

2.9 Carcinogens and non-carcinogens occurrences 22
2.10 Antibiotics contamination in water sources 23
2.10.1Antimicrobial resistance (AMR) 24
2.10.2 Antibiotic susceptibility of *E. coli* isolates 26
2.10.3 Effects of antimicrobial resistance 27
2.10.5 Antibiotic susceptibility testing (AST) 29

CHAPTER THREE 31
METHODOLOGY 31
3.1 Overview of the Study Area 31
3.1.1 Demographic characteristics 32
3.1.2 Physical and natural environment 33
3.1.3 Social and cultural structure 33
3.1.4 Research design 33
3.2 Sampling 34
3.2.1 Sampling technique and sites 34
3.2.2 Sampling collection procedure 34
3.2.3 Sample estimation 35
3.2.4 Geographic co-ordinate data 35
3.3 Laboratory analysis of samples 35
3.3.1 Physico-chemical analysis 36
3.3.2 Heavy metal analysis 36
3.3.2.1 Acid digestion of samples 36
3.3.2.2 Heavy metal concentration determination 36
3.4 Microbial analysis 37
3.4.1 Biochemical confirmatory test 37
3.4.1.1 Catalase test 37
3.4.1.2 Indole test 37
3.5 Antibiotic Susceptibility Testing 38
3.6 Data Management and Analysis 38
3.7 Human risk assessment methodologies 39

CHAPTER FOUR **41**
RESULTS **41**
4.1 Introduction 41
4.2 Bacterial Load and Prevalence of Hand-dug Wells and Boreholes 41
4.2.1 Bacterial load and prevalence of hand-dug wells 41
4.2.2 Bacterial load and prevalence of boreholes 42
4.3 Physical and Chemical Contaminants 43
4.3.1 Levels of pH of hand-dug wells 43
4.3.2 pH levels of boreholes 44
4.4.3 Turbidity levels in hand-dug wells 45
4.4.4 Turbidity levels in borehole water 45
4.4.5 Conductivity levels in hand-dug well water 46
4.4.6 Conductivity levels of boreholes 47
4.4.7 Concentration of iron (Fe) from hand-dug wells 47
4.4.8 Iron concentration from boreholes 48
4.4.9 Manganese (Mn) and Zinc (Zn) concentration from hand-dug wells 49
4.4.10 Manganese (Mn) and Zinc (Zn) concentration from boreholes 49
4.4.11Concentration of Cadmium (Cd) and copper (Cu) from hand-dug wells 50
4.5 One Sample T-Statistical Analysis for Hand-Dug Wells and Boreholes 52
4.5.1 T-test results for heavy metals from hand-dug wells 52
4.5.2 One-sample T-test results for heavy metals from boreholes 53
4.6 Chronic Daily Intake Levels, Hazard Quotient and Hazard Index Estimates for Hand-Dug Wells and Boreholes 53
4.6.1 Chronic daily intake levels, hazard quotient and hazard index estimates for hand-dug wells 53
4.6.2 Chronic daily intake levels, hazard quotient and hazard index estimates from boreholes 54
4.6 Carcinogenic risk values of cadmium (Cd) 59
4.7 Antibiotic Susceptibility Test (AST) 60
4.7.1 Antibiotic susceptibility test of *E. coli* isolates from hand-dug wells and boreholes 60

CHAPTER FIVE **61**
DISCUSSION **61**
5.1 Bacteriological Analysis of Hand-Dug Wells and Boreholes 61
5.1.1 Total coliform (TC) 61
5.1.2 Faecal coliform (FC) 61
5.1.3 Escherichia coli (E. coli) 62
5.2 Physico-chemical contaminants in Hand-dug wells and boreholes 63
5.2.1 pH 63
5.2.2 Turbidity 63
5.2.3 Conductivity 64
5.3 Heavy Metals 64
5.3.1 Iron (Fe) 64
5.3.2 Manganese (Mn) 65
5.3.3 Copper (Cu) 66
5.3.4 Zinc (Zn) 66
5.3.5 Cadmium (Cd) 67
5.4 Health Risk Assessment 67
5.4.1 Hazard identification 67
5.4.2 Exposure assessment 68
5.5 Chronic Daily Intake (CDI) 69
5.5.1 Chronic daily intake (CDI) – Hand-dug wells 69
5.5.2 Chronic daily intake (CDI) - Boreholes 69
5.6 Hazard Quotient (HQ) and Hazard Index (HI) 70
5.6.1 Hazard quotient and hazard index of Hand-dug wells 70
5.6.2 Hazard quotient and hazard index of boreholes 70
5.7 Carcinogenic Risk (CR) 70
5.7.1 Carcinogenic risk with hand-dug wells 70
5.7.2 Carcinogenic risk with boreholes 71
5.8 Antibiotic Susceptibility Test 71
5.8.1 Antibiotic susceptibility test of hand-dug wells and boreholes 71

CHAPTER SIX **73**
6.0 SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS **73**
6.1 Summary of Findings 73
6.2 Conclusion 74
6.3 Recommendations 74

REFERENCES **76**
APPENDIX ONE **93**
APPENDIX TWO **94**

LIST OF TABLES

Table 2. 1 Aid agencies influencing Ghanaian water law and policy.. 20

Table 4. 1 Bacterial counts and prevalence enumerated from hand-dug wells……………………..42

Table 4. 2 Bacterial counts and prevalence enumerated from boreholes 43

Table 4. 3 One sample T-test results for heavy metals from hand-dug well 52

Table 4. 4 T-test results for heavy metals from boreholes... 53

Table 4. 5 Exposure levels, hazard quotient and hazard index of adults to non-carcinogenic heavy metals from HDW... 55

Table 4. 6 Exposure levels, hazard quotient and hazard index of infants to non-carcinogenic heavy metals from HDW... 56

Table 4. 7 Exposure levels, hazard quotient and hazard index of adults to non-carcinogenic heavy metals from boreholes.. 57

Table 4. 8 Exposure levels, hazard quotient and hazard index of infants to non-carcinogenic heavy metals from boreholes.. 58

Table 4. 9 Antimicrobial agents, concentration and expressed response 59

Table 4. 10 Antimicrobial agents and expressed responses... 60

LIST OF FIGURES

Figure 2. 1 A map of Atankwidi basin showing zinc concentrations (Anim-Gyampo et al., 2019) 18

Figure 3. 1 A map of the study area 32

Figure 4. 1 pH levels of hand-dug wells 44

Figure 4. 2 pH levels of boreholes 44

Figure 4. 3 Turbidity levels of hand-dug wells 45

Figure 4. 4 Turbidity levels from boreholes 46

Figure 4. 5 Conductivity levels recorded from hand-dug wells 46

Figure 4. 6 Conductivity levels from boreholes 47

Figure 4. 7 Iron concentrations in sampled hand-dug wells 48

Figure 4. 8 Iron concentrations in boreholes 48

Figure 4. 9 Manganese concentration from hand-dug wells 49

Figure 4. 10 Manganese concentration from boreholes. 50

Figure 4. 11 Concentration of Cadmium and Copper from boreholes 51

Figure 4. 12 Concentrations of Cadmium and Copper from hand-dug wells 52

LIST OF PLATE

Plate 3. 1Bacteria growth on membrane filter 38

ABSTRACT

Groundwater is a natural resource useful in sustaining human life and livelihoods. The rising urban population, rapid urbanisation, and changing biophysical factors increase water demand and quality. This study assessed the groundwaters microbial and physicochemical contaminants, chemical risk of exposure and susceptibility of *Escherichia coli* to antibiotics. Cluster and purposive sampling techniques were used to select 20 groundwater sources from the study sites. The membrane filtration technique, portable probe meter, turbidimeter and acetylene-to-air flame techniques were used for microbial and physico-chemical analysis. Data generated were subjected to descriptive statistics and one-way t-test. Of the 11 borehole water samples, 36.4%, 63.6%, and 72.7% were within the permissible limit for total coliforms, faecal coliforms and *Escherichia coli*, respectively. For the hand-dug well water samples, 66.6%, 66.6% and 44.4% were within the stipulated values for total coliforms, faecal coliform and *E. coli*, respectively. Concerning the physicochemical parameters, all but turbidity, Fe, Mn and Cd had 22.2%, 11.1%, 44.4% and 22.2% of samples falling within the expected values. About 77.8% of the borehole tested had normal level of turbidity, 27.27% for iron, 9.09% for manganese and 9.09% for cadmium. All borehole samples'pH, conductivity, Cu and Zn levels fell within the acceptable range. Regarding hand-dug well water, the computed hazard quotient for Cu, Fe, Mn and Zn were less than 1 for adults and infants, indicating no likely health threat. Adults and infants computed hazard quotients for the boreholes were less than 1 except for Fe and Mn among infants at two separate points. The hazard index exceeded one at four the borehole points indicating the possible cumulative potential of adverse health risk. *Escherichia coli* isolates were sensitive to Ciprofloxacin, Gentamicin and Ofloxacin whereas Cefuroxime, Augmentin and Ceftazidime were resistant. The presence of coliform bacteria and the deviation of the physicochemical indicators from the stipulated values in some of the water sources suggests existence of insanitary conditions and lithogenic factors. Appropriate treatment installation is recommended to help bring the quality of the water sources to an acceptable range. There is also a need for strict adherence to hygienic protocol and proper disinfection at hand-dug well and borehole facilities. *E. coli* infection resulting from consumption of the water sources surveyed may be managed effectively with Ciprofloxacin, Gentamicin and ofloxacin.

CHAPTER ONE

INTRODUCTION

1.1 Background

Water is fundamental to the survival of humankind and has played a critical role in managing our ecosystem. Continuous access to adequate quantities of safe and good-quality drinking water is a basic necessity for human growth and well-being hence, it is an internationally accepted human right (UNDP, 2018). Access to safe drinking water can improve health and productivity. The most suitable water sources for humans are boreholes, rivers, ponds and rainwater. However, surface waters have served as a significant source of drinking water in many rural areas of Ghana. Aside from their potable use, surface waters serve for recreational and navigational purposes as well as a source of aquatic resources such as fish and shrimps, which offer livelihood support for fisher folks among others (Yeleliere et al., 2018; Abarike & Ampofo-Yeboah, 2016). Despite these characteristics, surface waters have been reported to be heavily polluted, resulting in water-borne and water-related diseases such as diarrhoea and bilharziasis hence, consumption of surface waters is recognised as a contributor to diseases (Jackson et al., 2020; Kadyampakeni et al., 2018; Awotwi et al., 2017; Asare-Donkor et al., 2016; Lie et al, 2011).

Ghana is conveniently well endowed with surface water resources, with the Volta River being the largest, occupying a surface area of 8,500 kilometre square (km2) and possessing an estimated volume of 150 billion metres cube (m3). Unfortunately, the Volta River, for example, and its tributaries are under severe stress due to competing demands and harsh climate conditions (Mul et al., 2015).

Per capita fresh water in the country is falling; the period from 1955 to 1990 witnessed a drop from 9,204 m^3 to 3,529 m^3, and projected to further drop to about 1,400 m^3 by 2025. Ghana and Burkina Faso are included in six west African countries cited by World Water to expect a shortage of freshwater by 2025 due to expected population increase (Boretti and Rosa, 2019). Literature from many studies including Anim-Gyampo et al., (2019) and Asare-Donkor et al., (2016), emphasise groundwater as a significant and reliable source of water supply for urban, peri-urban and rural areas. This assertion deeply justifies earlier statement by Tay, (2008) who presented the fact that the abstraction and use of groundwater have grown in prominence, due to its significance as a water source for human use. For example, Ghana's total groundwater abstraction is estimated to be 140 million m3 per year and represents about 25% of the total water supply. Current data reveals that about 33% of the country's population has access to pipe-borne water whereas 57% have access to non-pipe sources. Furthermore, Ghana's urban front has 40% access to pipe-borne water, while 58% has access to non-pipe water (UNICEF and WHO, 2019). This knowledge implies a mix or variety of water sources other than pipe water accessed by a considerable proportion of Ghanaians. Water sources such as hand-dug wells, boreholes and dug-outs stand the chance of being in this mix. Among these water sources, there is a reason for research works to prioritise hand-dug wells and boreholes due to their prevalence in developing areas of the Tamale metropolis. Additionally, since hand-dug wells and borehole water could be developed anywhere, it makes it possible to construct and secure for water vending. It has also been observed that about 63% of the accessible water sources is free from contaminants (UNICEF and WHO, 2019). In other words, approximately 37% of accessed water is contaminated.

World Economic Forum (2017) reports, covering seven years in a row highlighted that water crises are among the top five global risks. This is a severe problem in the developing world, in particular, where there is also a serious food crisis and social instability. Although water scarcity has been more acute in rural areas, emerging trends point to worsening water quality of the water in urban areas. The latter is due to changes in water characteristics due to land-use changes and climate change among others (Issah, 2016).

1.2 Problem Statement

All year round, the Tamale metropolis is challenged with a shortage of pipe-borne water due to the inability of the water service provider to keep pace with the rising demand from the increasing population. Tamale, the third fastest growing city in Ghana, is predicted to grow incrementally, relaying equal demand for water. The rising threat of climate change also deepens the effects on available surface water resources (Awotwi et al., 2015). To ease this burden, many Non-Governmental Organizations (NGOs), corporate organisations and some individuals have resorted to abstracting water from the ground for potable, domestic and industrial uses in the metropolis. However, the sustainability and the quality of the water at these sites remains questionable. This is because some people resort to the services of foreign nationals with doubtful expertise in the drilling and development of boreholes and hand-dug wells (Danert et al., 2020). Similarly, some human activities such as septic tank development, open discharge of liquid and solid waste, cattle ranch in house backyards and farming, have the potential to impair the quality of groundwater (Takal & Quaye-Ballard, 2018; Bright, 2014). The continuous access and consumption of such water are likely to affect ill health implications on users including children and the vulnerable.

Numerous research works on groundwater quality assessment have been conducted in the southern areas and towns such as Ejisu, Offinso, Kumasi, Teiman-Oyarifa, Ga–East, Kwabenya and Dodowa (Lutterodt et al., 2018; Duodu, 2014; Amfo-Otu et al., 2012; Ackah et al., 2011; Amankona, 2010; Nkansah et al., 2010; Anornu et al., 2009). Nevertheless, published research on groundwater quality and risk assessment in Tamale and its environs seems obsolete. To inform policy decisions, a need exists for a study aimed at providing current and detailed water quality data on groundwater sources.

1.3 The rationale of the study/Justification

Groundwater usage through boreholes and modern hand-dug wells is rising, rendering groundwater a critical water source for urban, rural and peri-urban water supply (Mensah et al., 2022). Despite their usefulness, they are prone to contamination from chemicals and microbial agents. Hence, detecting such contaminants, including Cd, Cu, Fe, and Mn and their prevalence over time is essential. One key reason is that such contaminants may undergo bioaccumulation in humans and be expressed in terms of adverse health effects such as cancer, or they may act as neurotoxins. Similarly, the detection of pathogenic bacteria such as *E. coli*, may give a clue as to the bacteriological safety of the water sources for human ingestion and the role of humans in the contamination process to help plan health promotion campaigns. Furthermore, information on the susceptibility of disease-causing bacteria to antimicrobial agents will also help/assist in treating patients in case of infection. The global Sustainable Development Goal (SDG) six targets ensure availability and sustainable water and sanitation management for all. Sustainable management encompasses understanding trends in terms of quality and quantity. SDG six appreciates improving water quality by reducing pollution, among other things.

The information generated through this study is expected to assist developers, experts, and public health management to effectively plan and manage the water supply chain within the Tamale area and its environment.

1.4 Hypothesis

The null hypotheses of the current study were:

- Borehole-sourced water is less or not contaminated and poses no adverse health risks.
- Hand-dug well-sourced water is less contaminated and poses no health risks.

The alternate hypotheses of the current study were:

- Borehole-sourced water is contaminated and poses adverse health risks.
- Hand-dug well-sourced water is contaminated and poses adverse health risks.

1.5 Research Questions

What is the prevailing water quality of boreholes and hand-dug wells in the Tamale Metropolis?

What is the chemical risk of exposure to children and adults in the metropolis?

Is there any possibility of enumerating *E. coli* with the potential to cause an infection and resist antibiotic treatment?

1.6 Objectives

1.6.1 General Objective

This study sought to evaluate the quality of groundwater sources in the Tamale metropolis, estimate the chemical risk of exposure to selected trace elements, and evaluate the antimicrobial susceptibility of E. coli isolates.

1.6.2 Specific Objectives

The specific objectives of the current studies were to:

1. Determine loads and concentrations of microbial contaminants in boreholes and hand-dug wells,
2. Determine some physico-chemical parameters of water in boreholes and hand-dug wells,
3. Compute chronic daily intake, hazard quotient and hazard index for children and adult consumers,
4. Determine the antibiotic susceptibility of isolated *E. coli*.

1.7 Scope and Limitation

With specific reference to the research problem and questions, the study evaluated the prevailing conditions at each sampling site, to assist in understanding the outcome from laboratory analysis. The study also buttressed findings with a literature review, secondary data and field observations. It covered the Tamale metropolis, including emerging suburbs. The metropolis is one of the region's most prominent districts, thus covers an estimated population of 371,351 (GSS, 2014). The study, however, could not explore a more comprehensive array of microbial and chemical contaminants.

1.8 Organisation of the Thesis

The entire study is structured into six chapters with each deliberating on separate modules of the study. The first chapter covers a detailed, yet brief discussion of the background to the study, problem statement, research questions, objectives, scope and limitations. Some relevant literature on water resources management, sources of water, water quality status of water systems and health risk assessment were included. The second chapter covers relevant literature reviewed with particular reference to the aim and specific objectives of the current study. The chapter also reviews the water situation in Ghana, water quality in Ghana and water supply in Northern Ghana. Chapter three describes sampling procedures, analytical methods, study design, and data analysis whereas chapter four presents the concentrations of physicochemical contaminants and microbial loads investigated from samples. Chapter five contain brief discussion of findings with references while chapter six summarises the major findings of the study and makes recommendations for policy action and further research. The chapter also provides a conclusion of the study.

CHAPTER TWO

LITERATURE REVIEW

2.1 Groundwater sources, occurrence and distribution

Groundwater constitutes about 97% of global freshwater followed by lakes, reservoirs, rivers and wetland. It is the source of 30.1% of all fresh water on Earth. It is also considered the most African continent's most resilient potable water source (Anim-Gyampo et al., 2019; Lapworth et al., 2017). It is contained beneath the surface of rocks and soil, and accumulates underground in aquifers. As aquifer material and groundwater quality are often closely related, understanding the geological characteristics of a study area is a prerequisite for a meaningful groundwater chemistry investigation. Studies have suggested Ghana's land area is underlain by three major geological terrains (Carrier et al., 2008; Nicola, 2005). The first terrain is comprised of Paleoproterozoic rocks (quartzites, phyllites, grits, conglomerates, schists, tuffs, graywackes, metamorphosed lavas and pyroclastic rocks) predominant in the south-western and the north-western part of the country. Further, gneisses and supracrustal rocks of mostly Neoproterozoic age are found in the south-east and east of the country. The second geological terrain consists of flat-lying shelf/marine sediments of very late Precambrian to Palaeozoic age, which occurs in the central and north-eastern part, while the third sequence, the mostly Cenozoic sediments, occupies a small strip along the coast (Nicola, 2005; Carrier et al., 2008). Many cities in the world, including the United States of America, Europe, China, Indonesia and Africa depend wholly or partially on groundwater for domestic, agricultural and industrial water supplies. In the USA, 22% of total national withdrawals come from groundwater sources. Some advanced countries like Bulgaria, Italy, Germany, Denmark and Austria generate

60%, 80%, 72%, 98% and 99% of their drinking water supplies from groundwater. Carrard et al., (2019) reported that, approximately 80% of potable water used by some European countries is drawn from groundwater sources. Groundwater is recognised as the sole most important supply for drinking water, particularly in areas with limited or polluted surface water sources. Comparatively, Africa's rural areas and low-income peri-urban communities are places of much dependence on groundwater (Gutu, 2023). Furthermore, the Great Manmade River of Libya was created from the Nubian Sandstone aquifer and supplies most of Libya for domestic, agricultural and industrial uses. In Ghana, the whole Keta basin towns, Wa, Breman Asikuma, Nkawkaw, Axim and most towns and district capitals rely on groundwater for domestic purposes. The expanding suburbs of our cities and the struggle for water in these peri-urban areas have driven those residents who can afford to seek alternate water supply in groundwater. Among the merits of groundwater over surface water, it requires little or no treatment to be suitable for potable use whereas surface waters generally require extensive treatment. It is often more reliable, closer to users, less vulnerable to pollution, and more resilient to climate variability than surface water (MacDonald et al., 2012). However, its demerits include significant operating costs, especially when pumping from deep aquifers.

2.2 Groundwater abstraction and utilisation

Groundwater is abstracted from all the hydro-geologic provinces of the country (Pavelic et al., 2012). The main structures for accessing groundwater are boreholes, hand-dug wells and dugouts. Abstraction systems over the country are over 15,000 in boreholes, greater than 60,000 for hand-dug wells and some dugouts (Pavelic et al., 2012). Two decades ago, Kortatsi (1994) reported 1,340 boreholes in the then Northern region, 1,350 in the Upper

West region and 1,680 in the Upper East region. It is logical and understandable that over the years, the number of groundwater abstraction structures may have steadily risen above these figures and hence an indicator of increasing reliance on groundwater as a source of water. Data from the Ghana Living Standard Survey seven (7) main report revealed that groundwater sources (mainly boreholes and hand-dug wells) constituted 36.4% of the main sources of drinking water supply in Ghana (GSS, 2019). Abstracted water from deep aquifers has been identified as a preferred means of domestic water supply particularly in urban areas, smaller towns and rural areas (Agyemang, 2021; Gyau-Boakye et al., 2008). Approximately 95% of borehole water use is for domestic purposes including drinking while 50% of hand-dug wells are for drinking and 66% for both drinking and domestic purposes. Often, boreholes are fitted with a hand pump or motor pump in cases where water is lifted over height into a storage tank and supplied to homes. Forms/brands of hand pumps often used include Afridev, Ghana-modified India mark II and Nira (Pavelic et al., 2012).

Watering of livestock with groundwater occurs mainly in the Upper East, Upper West, Northern and Greater Accra regions. Its uniqueness lies in the spillways constructed away from the drainage aprons of the boreholes to collect in troughs for use by livestock mainly goat, sheep, cattle and pigs (Kwoyiga and Stefan, 2018; Kortatsi, 1994).

Industrial use of groundwater in Ghana is a very recent phenomenon, in doing so is steadily rising. Some boreholes have been drilled solely for large-scale commercial bottled water industries (Gyau-Boakye et al., 2008 In Pavelic et al., 2012). Furthermore, previous studies revealed that major commercial bottled water industries in Ghana got their water supplies from groundwater sources in the Densu Basin (Darko and Dapaah-Siakwan, 2003).

2.3 Regulations and water rights

Ghana's water resources are often regulated and managed by the Water Resources Commission, WRC Act, (No. 522 of 1996) and the Water Use Regulations, Legislative Instrument (LI 1692 of 2001). Before the formulation of this act, bodies and firms desiring to abstract water for any use were not obliged to follow any procedure or seek any permission to do so. However, following the passage of this act, granting of water use permit is considered a tool meant to regulate water abstraction and control pollution of water bodies. Previous laws, in the form of community by-laws concentrated on surface water only. The passage of WRC Act, has filled the gap in the regulation of groundwater use. Section 12 of Act 522 stipulates that "the property in and control of all water resources is vested in the President on behalf of, and in trust of the people of Ghana". This implies that there is no private ownership of water in Ghana, still the president, or anyone so authorised, may grant right for water use (Ministry of Water Resources, Works and Housing, 2015). The WRC, mandate includes granting of water rights and water use permits. These permits are given to individuals and agencies for surface and groundwater abstraction for domestic, commercial, industrial and agricultural use; hydraulic works construction like damming; borehole drillers; aquaculture; recreational use and underwater timber harvesting. Few types of water use are exempted from the requirement of permit, which including water for fire-fighting and any water abstraction by manual means. Hand-dug wells for domestic water supply and belonging to individuals and communities are also exempted. Similarly, abstraction by mechanical means, where the withdrawal rate does not exceed 5 L s-1 as well as subsistence agriculture water use for land not exceeding one (1) ha, do not require a permit, though it should be registered.

In brief, LI 1827 of 2006 regulates and ensures the safe development of Ghana’s groundwater resources through the licensing of water drilling firms, stipulating the process of acquiring a drilling license and details on how to notify WRC of the intention to drill (Ministry of Water Resources, Works and Housing, 2015). Aside from statutory laws, customary laws and practices also govern water use in Ghana. These laws and practices encompass water conservation, pollution control, protection of catchments and protection of fisheries. They are enforced through sanctions usually dictated by fetish priests. The laws are more appropriate for small communities with robust traditional authority (Ministry of Water Resources, Works and Housing, 2015).

2.4 Water and Sanitation

Ghana’s water and sanitation have a long-term vision to ensure “universal access to safe drinking-water by 2025 and to eliminate open defecation by 2030”. This vision align with the Sustainable Development Goal (SDG) 6, the strategicwater sector development plan. Ghana's shared growth and development agenda and other national documents. Currently, the Government of Ghana's key agencies assisting with drinking-water and sanitation services include the Ministry of Water and Sanitation, Water Resources Commission, Ghana Water Company Limited, Community Water and Sanitation Agency, Ministry of Local Government and Rural Development, Environmental Health and Sanitation Directorate, Metropolitan, Municipal and District Assemblies, Ministry of Education/School Health Education Programme and the Ministry of Health/Ghana Health Service (Ministry of Water Resources, Works and Housing, 2015). As of 2015, global progress had been made into achieving 91% of the global population using improved drinking water compared to 1990; about 740 million mostly poor and marginalized people in sub-Sahara Africa still lack access to quality drinking water (MDG, 2015). Data presented in 2017 relay that, 81% of the Ghanaian population had access to at least basic drinking water. Under segregation, the rural and urban fractions had 68% and 93%, respectively, regarding access to such drinking water. However, 2% of the urban population had unimproved drinking water source compared to 8% in 2000. At the national level, 4% have at least a drinking water source as compared to 9% in the year 2000. In 2017, 57% of the Ghanaian population had no access to piped drinking water whereas 33% had access to pipe water. This is a remarkable improvement regarding the percentage (43% for access to pipe water and 31% for access to non-pipe water) recorded in the year 2000. Urban population with access to pipe and non-pipe were found to be 40% and 58% compared to the year 2000 where they scored 80% and 9% respectively (UNICEF and WHO, 2019). Anecdotal reasons from personal insight responsible for the increase from 9% to 58% is possibly from the rapid urbanization occurring in many urban areas of the country. Concerning the quality of accessed drinking water, it was deduced that 45 % of the population (national) drinking water source surveyed recorded the presence of contaminants. The dissection of literature revealed the least comments on the nature of the contaminants enumerated although previous national surveys had revealed arsenic and *E. coli*. Regarding the urban population, 37% of the populace drinking water source tested positive for water contaminants. Compared to the year 2000, there is a noted 6% drop without any noted notes on the possible causes for the reduction (UNICEF and WHO, 2019). Sanitation continues to challenge the Ghanaian government despite the increased dissemination of relevant information and interventions in the sub-sector. As at 2017, the Multiple Cluster Indicator seven (7) data generated pointed out that 15% of the national population still practised open defecation. Furthermore, the percentage of the urban populace that practised open defaecation was 7% compared to 9% during the year 2000. About 50% of the national population was identified to have used limited/shared sanitary facilities and 13 % utilized unimproved sanitary ware. At the urban level, 8% and 60% of the population used unimproved and limited/shared sanitary facilities (UNICEF and WHO, 2019). A 3% drop in the percentage of the surveyed populace practising shared use of such facilities using the year 2000 as a reference implies a slow response considering the number of years and the reflected change in percentage.

2.5 Water distribution in Northern Ghana

The sources of water for many Northern Ghanaian households have included pipe-borne inside and outside dwellings, public tap, borehole, rainwater, protected springs, bottled water, sachet water, tanker supplied or vendor-provided, hand-pumped well or open well, and spring, river or stream and dugout, pond, lake, dam or canal. Tamale urban encompassing the metropolis has 45.2% of its populace accessing pipe-borne outside their dwelling, 4.7% tapping from the public stand, 0.7% accessing from boreholes, 0.8% from tankers services or vendor providers and 0.6% from dug-outs or ponds (GSS, 2014). Water use in a typical Tamale home is likely to rise due to the intercensal growth of 3.5% which is above the national growth rate of 2.5% experienced. In addition, it is the sixth most populous district among the 216 districts in the country and has eleven (11) people in every house. This translates the average household size to 6 (GSS, 2014). Similarly, in the Upper East region, where conditions are alike, open wells and boreholes drilled and fitted with hand pumps dominate and are the most heavily relied upon. Sachet and bottled water are additional sources that are patronized for potable use. A range of 1.3 – 6.8L and 1.7 – 2.1L was established as the volume of water orally consumed by adults and infants, respectively (Craig et al., 2015). Regarding the daily per capita water consumption rate for the urban population, 75 litres is the standard set by Ghana Water Company Limited as a guide or threshold volume required for daily use. Unfortunately, finding from Awepuga (2015), in a survey revealed that about 46% of respondents who were inhabitants of Tamale and Sagnarigu, had access to a maximum daily supply of 100 litres for their daily household domestic activities whereas about 33% and 21% had daily access of 51-100 litres and over 100 litres, respectively. An evaluation of the same finding revealed an average household size (6 members) required 450L/day to support a healthy lifestyle. This authenticates that one-third of the urban population was inadequately supplied with the desired volume of water needed whereas about one-fifth were able to obtain volumes more than 100L. Socially, Tamale is characterised by periodic events such as family gatherings or meetings, naming ceremonies and funerals hence influencing volume of water required to maintain healthy households. Instead, recognised water vendors with uncompromised quality checks augment the water demanded by the population. Alternatively, neighbourhoods may collaborate to construct boreholes, mechanise and utilise at a shared cost. An attempt to estimate the prevailing neighbourhood water demand will require the water consumption per capita multiplied by the population to know the total domestic water demand for such emerging suburbs.

2.6 State of water quality

The quality of water resources, which hitherto was reasonably good, has recently shown signs of gradual deterioration partly due to the non-enforcement of regulations in the mining industry (Yeleliere et al., 2018). Water pollution of varying degrees is prevalent in almost all the river basins of Ghana. Still, it is more pronounced in urbanized river basins like the Densu and in areas where mining activities take place especially, in the Pra, Ankobra, and Birim basins (Asare-Donkor et al., 2015; Bortey-Sam & Nakayama, 2015). Furthermore, dumping domestic, industrial and agricultural wastes into rivers and streams, particularly the Southwestern and coastal river systems has resulted in high pollution levels in many of the nation's water resources that require attention. Problems associated with the quality of groundwater are generally localised. For example, in the Bongo District of the Upper East Region and within the White Volta Basin, concentrations of 1.5 to 5.0 mg/L have been found in boreholes in the Bongo granitic formation as against the GSA and WHO guideline value of 1.5 mg/L (Alfredo et al., 2014). The Bolgatanga area had recorded iron (Fe) concentration beyond the regulatory limit. Similarly, earlier studies that assessed nitrate-nitrogen and manganese in the same area implicated the same parameters as they exceeded the regulatory limits. A study undertaken on ground and surface water within the Northern region and reported by Cobbina et al., (2013) enumerated heavy metals (chemical contaminants) such as mercury (Hg), Arsenic (As), Copper (Cu) and lead (Pb). Their findings reported that Cu and As concentrations occurred below the national regulatory limits whereas Cd and Pb concentrations measured high due to the illegal gold mining and its related activities in the jurisdiction of the study area. This observation supports that illegal small scale gold mining is a human or anthropogenic factor and is the cause of this localized pollution in surface and groundwater sources. In another similar and recent study of groundwater quality in the Atankwidi basin within the Upper East region, Anim-Gyampo et al., (2019) outlined the prevalence of fluoride (> 1.5mg/L) in communities along the north-eastern part of his study area (Atankwidi basin). The underlying geology/rock were identified as bearing fluoride minerals contributing to the unhealthy levels of fluoride in the Bolgatanga and Bongo areas. Findings of Anim-Gyampo et al., (2019) on fluoride concentrations agreed with Apambire, (1996) whose study revealed that Bongo formation contained 2-24 times higher levels in adjacent rock formations. This indicates that a natural factor (geogenic) s the cause of this contamination.

Regarding heavy metals (As, Pb and Zn), a slight concentration of Zn above the regulatory set limit of 0.01 mg/L was identified as sourced from leachates from agricultural activities that utilized extensive agro-chemicals. Lead (Pb) occurred in a relatively higher concentration beyond the regulatory limit of 0.006 in 37.5% of surface and groundwater used in the survey. Overall, a mix of both human and natural factors were identified as being the causes of contamination of the water in the Northern part of Ghana. Rural communities' investments sum of about 5% (total costs for borehole construction) lost during capping depicts a loss of water source and money (Alfredo et al., (2014). Accessible, economical, and efficient treatment techniques are the likely interventions that can assist in restoring such boreholes to good use through quality water provision. Per thorough literature analysis, the enforcement of small-scale mining by-laws is proposed to ensure environmental dignity and quality for Northern Ghana.

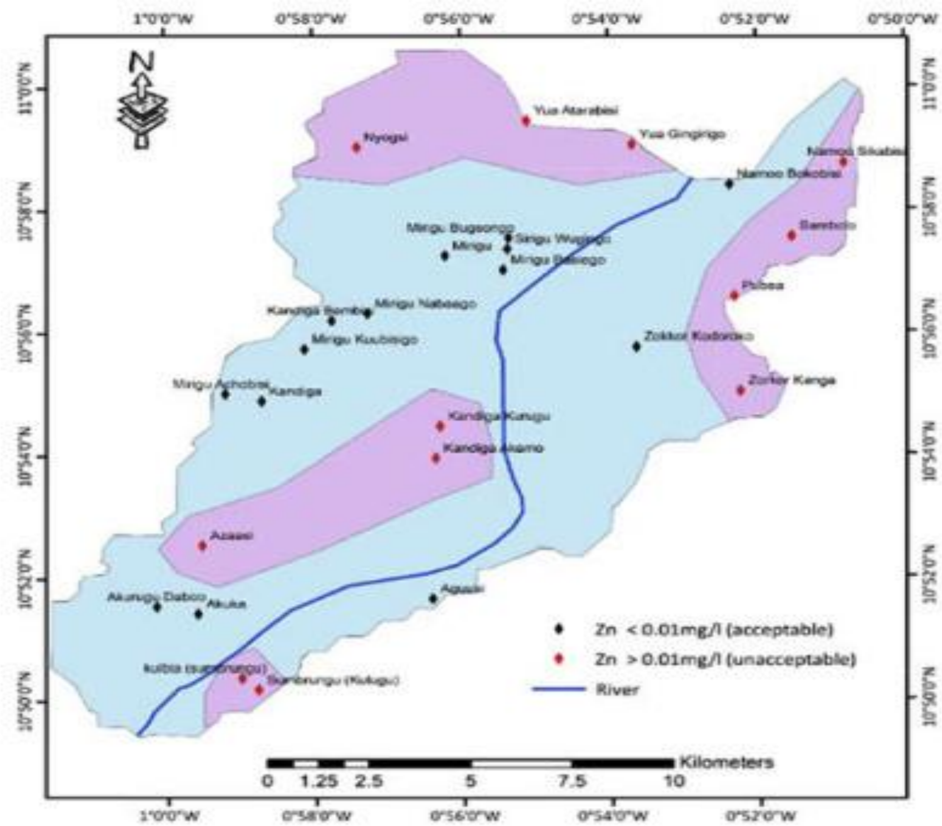

Figure 2. 1 A map of the Atankwidi basin showing zinc concentrations (Anim-Gyampo et al., 2019)

2.7 Ghana's water policy

Ghana's water policy has a unique overall goal to "achieve sustainable development, management and use of Ghana's water resources to improve health and livelihoods, reduce vulnerability while assuring good governance for present and future generations". It is formulated with consistency with then Ghana poverty reduction strategy (GPRS) and desires to be achieved with the addressing of urban water supply, community water and sanitation and water resources management. Key objectives of the water policy include ensuring water availability in sufficient quantity and quality for the cultivation of food, watering livestock and sustainable freshwater fisheries. Last but not the least, it is to ensure the availability of water in sufficient quantity and quality to support the functions of the eco-systems in providing alternative livelihoods (Ministry of Water Resources, Works and Housing, 2015).

A review of Ghana's water policy revealed that the period of post-independence (1957 – 1998) was characterised by the establishment of needed agencies with specific roles for water supply and environmental management. Further, it pointed to the period immediately after 1959 as an action time; during which the country accepted WHO recommendations and transformed the water supply division under the Public Works Department (PWD) into the Ghana Water and Sewerage Corporation. The role of different government agencies and international aid organizations had been granted prominent influence in water management (Scheumann et al., 2008). However, much of the former's assistance was skewed to areas of their choice. Simply, foreign aid geared towards what foreign investors are prepared to finance rather than what has been determined to be strategic directions of government (DANIDA, 2002). Ghana's Community Water and Sanitation Agency (CWSA) and the Public Utility regulatory Commission (PURC), Water Resources Commission (WRC) and the Water Sector Rehabilitation Project (WSRP) are all products of these major influences that have led to an appreciable number of reforms and the restructuring of the water sector, and the promulgation of laws and policies (Scheumann et al., 2008).

Table 2. 1 Aid agencies influencing Ghanaian water law and policy

Donor	Influence
African Development Bank	Implementation of the National Community Water and Sanitation programme (NCWSP) in the Ashanti region
African Development Bank	Implementation of the National Community Water and Sanitation programme (NCWSP) in the Northern, Upper East and West regions
Agence Francaise de Development	Implementation of the National Community Water and Sanitation programme (NCWSP) in the Western region
European Union (EU)	Involved in Community Water and Sanitation Programme; Implementation of NCWSP in the Northern, Brong-Ahafo, Western and Ashanti regions
International Monetary Fund (IMF)	Assisted with conditional loans on automatic tariff adjustments and PSP in the service sector
Wateraid	International non-governmental organization promoting water and sanitation project
World Vision International	Funding water provision in rural communities
World Bank group (WB)	Together with IDA and IMF are initiator and leading implementer of water sector reforms

Source: (Agyenim and Gupta, 2010)

Ghana's water policy in the quest to develop the sector is challenged by the principle covering the policy as it seeks to operate on cost recovery. Adding to this burden, Ghana's vote in favour to pass the notion of a human right to water and sanitation in its further implementation of the policy during the 2010 UN resolution (Agyenim and Gupta, 2010) impacted more effect. The setback identified in literature review is reconciliating the principle on cost recovery and the right to water and sanitation. It is suggested based on literature evaluation that the country should cross-subsidize, from a source of income or tap foreign help for the implementation of the right to water.

2.8 Water stress challenge

Water stress is described as a lack of freshwater resources to meet water demand. World Economic Forum (WEF) listed this as a global risk in terms of potential impact over the next decade (Companies and Group, 2019). Water stress affects about two billion people (about one-fifth of the world's population) worldwide and this figure is projected to rise. A trend analysis for the past two decades (1996-2016) shows that it has increased for most countries, notably African countries constituting 15 out of 26 countries. The literature reviewed assert that water stress stands at almost 13%, despite significant regional differences (UNESCO, 2022). It was also revealed that human interferences with the water cycle are the common causal agent. Globally, 32 countries are experiencing water stress within the range of 25-70%, twenty-two countries with a range beyond 70% and perceived as seriously stressed; 15 countries with a figure beyond 100%, of which 4 countries (Kuwait, Libya, Saudi Arabia and the United Arab Emirates) have their water stress above 1,000%. Africa's sub-Saharan region has a low level of water stress of about 3%. Water scarcity has many impacts on the environment such as adverse effects on rivers, ponds and wetlands where it renders such resource polluted, habitat loss and loss of ecosystem services such as protection from storms and flooding. The likely justification for this increment is increased economic activities, growing populations and enhanced water measuring techniques, along with the effects of climate change. The proposed remedy for the challenge with water stress is to improve water-use efficiency while shifting economic activities to less water consuming sectors.

2.9 Carcinogens and non-carcinogens occurrences

The International Agency for Research on Cancer (IARC) defines carcinogenic element as any agent (physical, chemical and biological) with the potential to cause cancer. The agency classifies these agents appropriately as either carcinogenic or non-carcinogenic borne out of evidence in animal "models" and sufficient evidence in men after exposure (IARC, 1991). WHO has compiled a list of the 10 major chemicals of concern among which Pb, Cr and Cd are considered highly hazardous human carcinogens (WHO, 2007). Studies on major chemical contaminants determination and its potential health risks from water sources and environmental resources in Ghana have been concentrated in the southern part of Ghana covering Greater Accra, Volta, Eastern, Western and Ashanti regions (Agyemang, 2020; Affum et al., 2017; Asare-Donkor et al., 2016; Duodu, 2014). Literature evidenced that chemical contaminants investigated have included Cd, Pb, Cu, Ni and Cr. The least determined of these chemical contaminants have included Cd, Cr, Ni, Ar whiles Fe, Mn, Zn have frequently been researched and have expressed higher concentrations (Anim-Gyampo et al., 2019; Cobbina et al., 2013). Except for Mark and Adadow, (2010) that investigated 22 heavy metals, many other studies investigated for 3–6 metals in water sources. Shallow hand-dug wells and boreholes dominated whereas dugouts and rivers were the least involved in many of these studies. Much of data reviewed worked on ingestion as the route of exposure and a few considering both oral and dermal as exposure routes (Agyemang, 2020; Anim-Gyampo et al., 2019; Obiri et al., 2016; Cobbina et al., 2011). The sample size has ranged from 5 to 161 while the air acetylene flame method was observed as the highest technique employed in the chemical contaminants including non-carcinogenic heavy metals concentrations determination.

Non-carcinogenic risk exposure values have range from 10^{E-01} to 10^{E-8} although many reported within 10^{E-01} and 10^{E-03}. On the contrary, carcinogenic risk values in many of such research implicated Pb and Cd for posing risk beyond the tolerable point as in the case of Akoto et al., (2019), Doyi et al., (2018) and Asare-Donkor et al., (2016). Some other research expressed lithogenic and anthropogenic factors as sources of these major chemical contaminants. Anthropogenic inputs identified by the review included industrial activities, fuel stations and mechanical workshops (Nkansah et al., 2017).

A further review of literature on the occurrence and determination of heavy metals in environmental resources (dust/soil) (Nkansah et al., 2017), vegetables and fruits (Naangmenyele et al., 2021; Sultana et al., 2017; Lente et al., 2014) alongside potential health risks from chronic exposure was carried out. Concerning dust /soils, carcinogenic metals (Pb, As, Cd, Cr, Ni and Co) had been detected across dust and soils in areas irrigated with wastewater, beach areas, and urban areas (Nkansah et al., 2017). Similarly, vegetables and fruits samples have recorded the prevalence of heavy metals but at relatively low concentrations. An evaluation of the analytical techniques applied in vegetables/ fruits heavy metal monitoring unravelled the use of the sophisticated Integrated Coupled Plasma, (ICP-MS) analytical device. Much of the reviewed literature revealed investigations of heavy metals that went up and beyond nine (9) trace metals including Pb, Cd and As (Nkansah et al., 2017; Duodu, 2014; Lente et al., 2014).

2.10 Antibiotics contamination in water sources

For some time, the occurrence and fate of antibiotics in the aquatic environment have been subjected to investigations in Ghana (Quarcoo et al., 2022; Adomako et al., 2021; Banu et al., 2021). The environment has played different functions in the emergence, spread and resistance of antibiotics. Firstly, it has served as a receiving receptacle of resistant bacteria from animals and humans that has ingested antibiotics. The environment also expedites antibiotics and resistance genes dispersal via air, groundwater, surface water antimicrobials (Antimicrobial Resistance Global Report on Surveilliance, 2014). Plain lands, residence environs among others during certain seasons of the year, retrieve water directly from the contaminated environment and use with no or inadequate treatment (Schwartz et al., 2003). Extensive literature search has identified other sources of antibiotics residues to groundwater as leaching from manure, or through sewage disposal on land. Further to this, antibiotics used in human and veterinary medication have been identified to go through percolation in soils resulting in groundwater contamination (Karimi et al., 2023: Alder et al., 2000). The spread of antibiotic-resistant bacteria is troubling the public health status of several individuals and even being highlighted as an emerging contaminant (Adzitey et al., 2014; Zou et al., 2011). Indeed, natural environments like the aquatic one represent a reservoir of antibiotic-resistant bacteria and have even been detected in drinking water (Odonkor and Addo, 2018; Shi et al., 2013). The likely risk to consumers of such water is the potential direct transmission of antibiotic-resistant pathogens to humans that may decrease the efficiency of antibiotic therapy and or promote the transmission of antibiotic resistance genes to commensals or opportunistic bacteria (Machado and Bordalo, 2014).

2.10.1Antimicrobial resistance (AMR)

AMR is defined as the resistance of a microorganism to an antimicrobial drug that was originally effective for treatment of infections caused by it. AMR may be intrinsic but natural resistance develop self-ability for deoxyribonucleic acid (DNA) recombination, and genetic mutation. Otherwise, intrinsic resistance occurs when the target of drug action is inaccessible. Alkhaleefah, (2015) reiterates that genetic mechanisms hastening bacterial resistance are gene transfer (vertical or horizontal) and mutation. Literature review identified two (2) main approaches used in the analytical determination of antibiotic resistant bacteria and genes; culture-based and molecular-based methods. It was further unravelled that, genetic based tests focus on the discovery of genetic elements, genetic markers that code for antibiotic resistance. Culture-based techniques and molecular techniques can be utilized together for determining microorganisms, genes that encode resistance in organisms of interest (Alkhaleefah, 2015). Widespread use of antibiotics has undoubtedly resulted in epidemics of antimicrobial resistance worldwide (Danner et al., 2019). Estimates of global antibiotics consumption range between 100,000 – 200,000 ton per annum, of which almost 50% is used for veterinary medicine and growth promoters. Regarding human intake, global consumption shot up by 36% between 2000 and 2010 which asserts antibiotic pollution as an emerging challenge (Van Boeckel et al., 2014). The antibiotic parent compound, its metabolites may remain stable, bypass water treatment processes, and leak into the environment (Karimi et al., 2023). Concerning consequences, AMR bacteria poses a significant threat to the global public health (Danner et al., 2019).

This is exhibited through many folds though not limited to the following: the relevance of water, wastewater and wastes as pathways for AMR human exposure (as compared to other routes such as food consumption). Literature asserts about three (3) major pathways for antibiotics into freshwater: effluents from wastewater treatment (WWT), chemical manufacturing plants and animal husbandry and aquaculture (Karimi et al., 2023).

Synthesising gathered literature, it can be reasoned that the ageing and non-functioning WWT in many areas of the Ghana easily allows for the 50 – 80% of total parent compounds excreted via urine and faecal matter for antibiotics such as ciprofloxacin and tetracycline (80–90%) into our environment including water sources (Karimi et al., 2023). The high rate of open defecation practice in Northern Ghana, may enhance terrestrial landscape run-off to foster antibiotic pollution in open waters (Danner et al., 2019). A review and personal analysis from studied literature supports the need for strict halt of antibiotics sale without prescription and ban of open defaecation in all areas.

2.10.2 Antibiotic susceptibility of E. coli isolates

E. coli are gram negative, non-spore forming bacteria, which ferment lactose at 37 ^{o}C. *E. coli* strains include enterotoxigenic *E. coli*, enteroinvasive *E. coli*, enteropathogenic *E. coli*, diffusely adherent *E. coli*, or verocytotoxigenic *E. coli*. Other biological characteristics of this group of bacteria include low infective dose, relatively longer survival time in the environment (Avery et al., 2005). It does not produce hydrogen sulphide, urease and cannot use citrate as sole carbon source. Person-to-person contact can lead to transmission of the pathogen via oral-faecal route (Adzitey et al., 2015). The reported infectious dose that can effect disease symptoms in humans has been reported to be as low as 4 to 24 colony forming units (CFU).

Disease symptoms takes different forms such as enteric infection (diarrhoea or gastroenteritis), haemolytic uremic syndrome, and urinary tract infection. Some strains have been identified to produce verotoxins and shiga toxins that are subsequently responsible for severe bloody diarrhoea (Doughari et al., 2011). Antibiotic resistance with *E.coli* bacteria has increased in recent times (Mensah-Attipoe et al., 2020).

Moreso, the emergence and diffusion of multi-drug resistant strains of *E. coli*, treatments of infections in community settings have been complicated (Agyepong et al., 2018). Many publications on shiga toxin *Esherichia coli* (STEC) have provide evidence of the pathogen in humans, animals, meat and environment (water). Fortunately for Ghana, a study of STEC along the coastal savannah did not find any isolation but this does not guarantee the absence of the pathogen (Addo et al., 2011). Concerning isolation procedures, Sorbitol MacConkey agar and Methylene blue agar were highly noted for the isolation of *E. coli* according to Mensah-Attipoe et al., (2020) while a few run with the application of molecular methods such as Polymerase chain reaction (PCR) (Abana et al., 2019). Among the WHO prioritized list of pathogens, George et al., (2012) and Opintan et al., (2015) reiterates *E. coli* as the pathogen that expressed multiple drug resistance (MDR).

2.10.3 Effects of antimicrobial resistance

Antimicrobial resistance (AMR) is a major threat to human development as it alters our ability to treat a range of infections caused by bacteria, parasites, viruses and fungi. Treatments for the growing list of infections, including water-borne and foodborne diseases, urinary tract infections, have become less effective due to resistance (Mahmoud et al., 2020; Ugwu et al., 2017). The efficacy of some common antimicrobials is threatened because of AMR among these WHO prioritized pathogens; *Escherichia coli*, *Staphylococcu aureus, streptococcus pneumoniae*, and non-typhoidal *Salmonella* (NTS).

These microorganisms have become resistant to vital antimicrobials (Antimicrobial Resistance Global Report on Surveilliance, 2014). The prevailing cost of health care for patients with resistant infections is higher than care for patients with non-resistant infections because of the relatively long duration of illness, additional tests and the need for additional but expensive medication. The rise in resistance aside from hindering infections treatment extends societal and economic effects and imperils the achievement of the Sustainable Development Goals (SDGs) (Mensah-Attipoe et al., 2020; Ayukekbong et al., 2017).

2.10.4 Response to antimicrobial resistance

World leaders have acknowledged the quick need to improve antibiotic use and collectively work on AMR at the 2015 United Nations General Assembly. These global leaders have expressed a stout political commitment to fight AMR in unison, built on the WHO global action plan (GAP) on antimicrobial resistance, adopted at the World Health Assembly (WHA68.7). This WHA resolution urges member states to align their national action plans on AMR with the GAP, and engage the tripartite organizations - WHO, Food and Agriculture Organization of the United Nations (FAO) and World Organization for Animal Health (OIE) - in responding to AMR (WHO, 2015 In Wuijts et al., 2017).

Here in Ghana, the government has followed suit by preparing a policy document on antimicrobial use and resistance since 2017. This first edition of the policy, developed by the government's Ministry of Health actually expresses the intent of Ghana's government. Unfortunately, it has reached a point in time where reformulation is required. A national action plan (NAP) on antimicrobial use and resistance also developed in the same year, interprets the policy directives recommended in the first policy document drafted from 2013 - 2016. The NAP expects all relevant sectors to align to this action plan to preserve this important group of medicines. It is projected that the NAP will effectively be revised after a five-year period, upon regular assessments on its implementation progress (Ghana

Ministry of Health, Ministry of Food and Agriculture, Ministry of Environment, Science, Technology and Innovation, 2017).

2.10.5 Antibiotic susceptibility testing (AST)

Antibiotic susceptibility testing (AST) is required for effective management of infectious diseases. It involves antimicrobial agents being tested against individual bacterial isolates with the aim of detecting possible drug resistance in pathogens and assure susceptibility to drugs of interest (Adzitey et al., 2015). Broth dilution test, otherwise known as microbroth/ tube–dilution method was the earliest technique used in AST. However, its weakness is the use of turbidity as a physical indicator of bacteria growth in test tubes. It also imposed load of drudgery, with the manual task of preparing serial dilutions of the antibiotic solutions, and requiring much space for the work as well as the possibility of errors in the antibiotic serial dilutions preparations. This technique also generated quantitative results (minimum inhibitory concentration, (MIC). A more frequently used technique, disk diffusion (DD) is commonly utilised considering its cost savings, test simplicity and flexibility since it does not require any special tool as compared to the automated instrument systems. DD also provides flexibility in disk selection for testing, quantitative results (eg, MIC), and qualitative assessment using the categories susceptible, intermediate, or resistant. Arguably, another critical step in AST is interpretation of results. The diameter of the zone relates to the susceptibility of the isolate in the DD method. Considering the DD technique, its MIC values and disk diffusion zone diameters are interpreted with the aid of table with values that relate to proven clinical efficacy of each antibiotic and for various bacterial species (CLSA, 2009). Automated instruments systems involve the use of enhanced computing software thus requiring much technical know-how. The system relays the advantage of assessing rapid susceptibility test results but considerable direct cost savings. Among its demerits are the narrowed ability to sense antimicrobial resistance of beta-lactamases and vancomycin. Despite prevailing challenges, much recent instruments have been enhanced through modification, extended incubation time (10 hours) that also contradicts the use of term “rapid” for such technique or system (Reller et al., 2009). During the interpretive aspect of the test, the terms “susceptible” express that a patient’s organism should respond to therapy with the chosen antibiotic using the dosage recommended normal for the infection type and species whereas “resistant” express that a patient’s organism with a MIC or zone size should not be inhibited with the doses used with that drug. A test that exhibits Intermediate” indicates the microbe of interest falls within the susceptibility range (CLSA, 2009). Notwithstanding the technique applied in the antibiotic susceptibility test, tables used for susceptibility test interpretations must represent the most current or updated criteria since CLSI documents are frequently updated (CLSA, 2009).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Overview of the Study Area

Tamale is the regional capital of the Northern region, and doubles as the capital for the Tamale Metropolitan Assembly (TaMA), one of 26 local government units in the Northern region. It has grown to become the third-largest urban centre in Ghana after Accra and Kumasi growing from less than 2000 people in 1907 to about 232,252 in 2010 (Ghana Statistical Service (GSS), 2013a). The Tamale Metropolitan Area (TaMA) is the second-fastest-growing metropolis in Ghana after Kumasi (GSS 2013a, 2013b, 2013c). TaMA is located within 9°16′N and 9°34′N and longitudes 0°34′W and 0°57′W (Fig. 1) and covers a total area of 922 km2. It is bordered to the north by Savelugu-Nanton Municipality; to the east by Mion District; to the south by East and Central Gonja Districts; to the west by Tolon District and to the north-west by Kumbungu District. TaMA is composed of Tamale, 17 peri-urban communities and 115 villages (Fuseini et al., 2017; GSS, 2014).

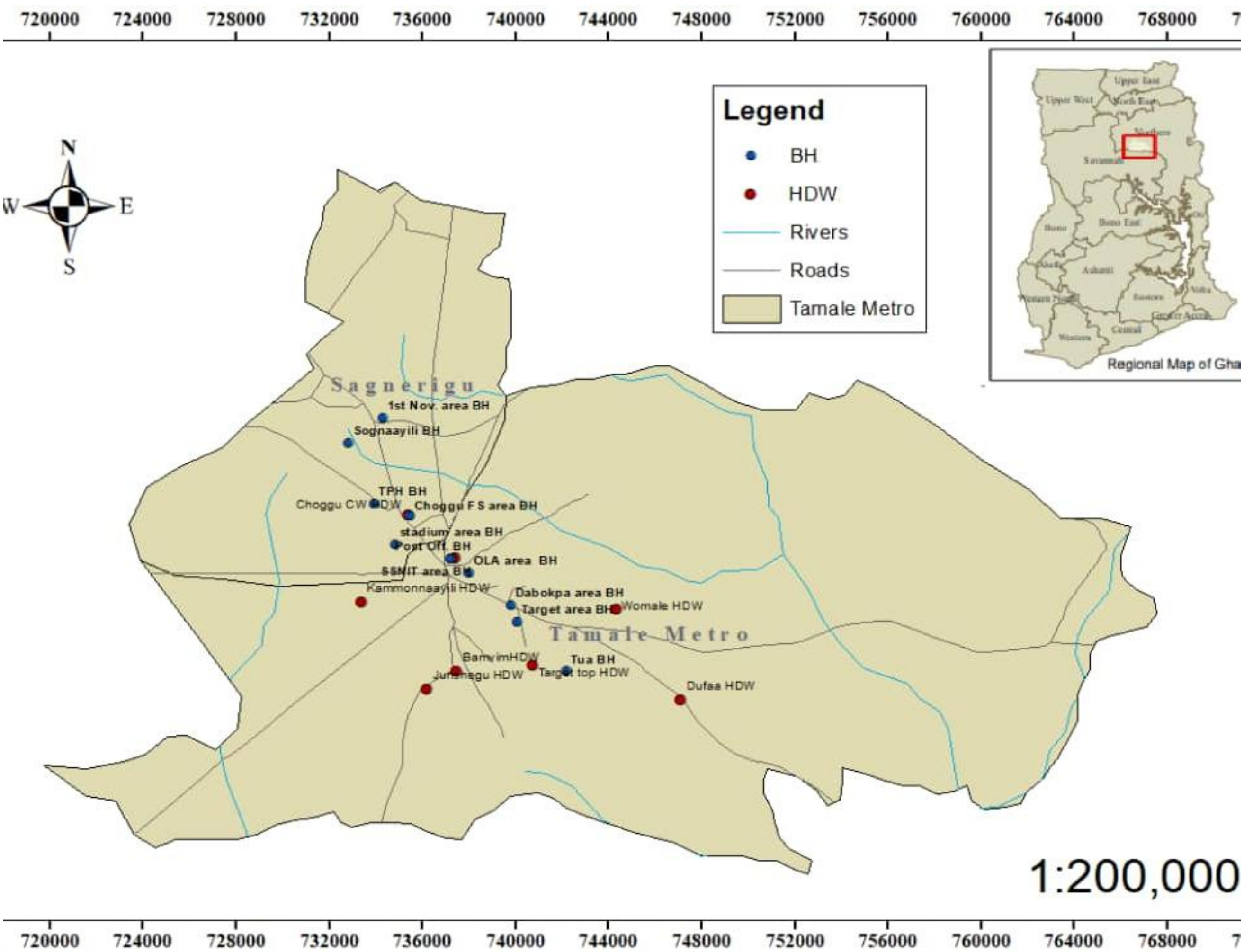

Figure 3. 1 A map of the study area

3.1.1 Demographic characteristics

The total population of the metropolis is 223,252, of which 111,109 and 112,143 are males and females, respectively. The proportion of the population living in the urban area (80.9%) exceeded that of rural portion (19.1%) of the metropolis. Similarly, the metropolis had 21,991 households living in 19,387 houses. The average household size in the metropolis is 6 persons per household. Children constitute the largest household structure accounting for about 40.4% (GSS, 2014). Persons per household. Children constitute the largest household structure accounting for 40.4% (GSS, 2014).

3.1.2 Physical and natural environment

The region is characterised by a uni-modal rainfall regime lasting 3-4 months and a long dry period lasting 6-7 months in a year (Kadyampakei et al., 2017). The Tamale land is undulating with a few isolated hills. The metropolis experiences only one rainfall season year, characterized by high humidity, slight sunshine and heavy thunderstorms. In contrast, the dry season is characterized by dry harmattan winds from November-February and high sunshine from March-May. The Metropolis lies within the savannah woodland ecological area. The trees in this area and for that matter, the Metropolis are short scattered wood lots. Dawadawa, Nim, Acacia, Mahogany, Shea tree and Baobab are the prevailing tree types in this area. The main soil types in the Metropolis are sandstone, gravel, mudstone and shale.

3.1.3 Social and cultural structure

The Dagombas are the majority ethnic group in the Tamale metropolitan area. A few other groups like the Gonjas, Mamprusis, Akan, and Dagaabas also reside in the town. The area has rich cultural practice reflected in some activities like annual festivals (fire festival, Damba festival) and naming ceremonies. Tamale is dominated by Muslims (90.5%), followed by Christians (9.3%) and Traditionalists (0.3%) (GSS, 2014).

3.1.4 Research design

A cross-sectional design was applied in this study to ascertain the groundwater quality of the Tamale Metropolis. Samples were obtained during the mid-part of the year's dry season.

3.2 Sampling

Water samples were collected in 500 ml sterile screw-capped plastic containers for physico-chemical analysis whereas samples for bacteriological analysis were collected in sterilised 500 ml bottles. These samples were transported on ice packs in a cooler box to the water quality laboratory for analysis.

3.2.1 Sampling technique and sites

Cluster and Purposive sampling techniques were used to identify boreholes and hand-dug wells occurring in different suburbs of the Tamale metropolitan. Samples from hand-dug wells were obtained from the following suburbs: Vittin Target, Banvim, Womale, Queen Elizabeth, Janshegu, Kammonayili, Choggu, Dufaa, and Gbayenmile. Borehole water samples were taken in Dabokpa, SSNIT, First November, Choggu, Tamin, Urban Road, Post office, Stadium, Tua, Poly and Sognayili areas.

3.2.2 Sampling collection procedure

Borehole water samples intended for physico-chemical analysis were taken after rinsing the sampling bottles with water from the borehole and then filling them to the desired limit. Similarly, water samples collected for microbial analysis were taken after flaming the nozzle of the hand pump before cleaning the nozzle with 70% ethanol-soaked cotton-wool and allowing the water to flow for a few seconds. Concerning hand-dug well water samples meant for microbial analysis, water samples were collected with a 400 ml metallic cup hooked to a fabricated handle with a rope. A few millilitres of 70% ethanol were sprayed into the cup, flamed and lowered after the flame died off to the required depth for water collection and refilling into a sterile sampling bottle.

Afterwards, water samples were used in rinsing and filling bottles for physico-chemical analysis. All water samples were collected in the morning irrespective of the analysis type.

3.2.3 Sample estimation

The sample estimates were based on assumptions that hand-dug wells prevail in many houses within the study area due to the low cost of hand-dug wells compared to boreholes. However, the position of boreholes and the general public level of accessibility to the boreholes influenced the study decision of the proportion to sample, to obtain a relatively considerable population size for the research. Based on this, consideration was granted to consider a relatively higher number of boreholes over hand-dug wells.

3.2.4 Geographic co-ordinate data

A portable Garmin Etrex handheld Global Position System device was used to capture geographic co-ordinates. With the aid of the ArcGIS software, a map was developed for the study area.

3.3 Laboratory analysis of samples

All physical, chemical and microbiological analytical procedures are detailed and provided in the American Public Health Association - Standards for the examination of water and wastewater, 23rd edition, (APHA, 2017). The physical parameters were determined with the aid of scientific instruments. In contracts, specifically Fe, Mn, Zn, Cu and Cd were assessed using the air-acetylene flame technique with a Shimadzu atomic absorption spectrophotometer.

3.3.1 Physico-chemical analysis

All physical and chemical analytical procedures are detailed and provided in the American Public Health Association Standards for the examination of water and wastewater, 23rd edition. Turbidity, pH and conductivity were taken in situ using a portable Wagtech brand multi-kit while the remaining (Iron, Manganese, Lead and Copper) were carried out in the laboratory.

3.3.2 Heavy metal analysis

3.3.2.1 Acid digestion of samples

Approximately, one hundred (100 ml) of the sample was filtered through Whatman branded 0.45 µm membrane filter paper. Five (5 ml) of concentrated nitric acid (HNO3) was added to the filtrate and heated using a heating mantle until the volume was reduced to fifteen to twenty (15-20 ml). The digested sample was allowed to cool at room temperature and filtered through Whatman's 0.45 µm filter paper. The final volume was adjusted to 100 ml with double distilled water and ready for heavy metal concentrations determination.

3.3.2.2 Heavy metal concentration determination

The Shimadzu AAS which uses air acetylene flame was used to analyze the samples for Fe, Mn, Cd, and Cu concentrations. The appropriate wavelengths of the various elements were selected and standard curves generated by running prepared standard solutions of the various metals. The absorbance values of the metals in the water samples was determined and compared with the standard absorbance of the various metals. This procedure was repeated for each sample and the average concentration considered the actual concentration of the heavy metal.

3.4 Microbial analysis

Microbial analysis was run using the membrane filtration technique. Faecal-sourced bacteria selected were plated on appropriate agar media: Brillance coliform/E.coli media for both Total coliform and E. coli, whereas MFc was used for faecal coliform. Bacteria growth was noted and characterised by colony colour with the aid of hand lens, and a colony counter (Plate 1).

3.4.1 Biochemical confirmatory test

Biochemical tests; indole and catalase tests were performed on isolated *E. coli* bacteria.

3.4.1.1 Catalase test

A loopful of bacteria isolate was placed on a dry slide. One drop of hydrogen peroxide solution was added to the isolate. A quick formation of bubbles after few seconds proved positive for the catalase test.

3.4.1.2 Indole test

A loopful of bacteria isolate was inoculated in 4 ml of tryptone water and incubated in a 37 ^{o}C (degree celcius) incubator for 22-24 hours. One drop of Kovacs Reagent was added after incubation and the formation of a red ring after fifteen (15) minutes indicated a positive indole test.

3.5 Antibiotic Susceptibility Testing

With the Kirby-Bauer disk diffusion method, confirmed *E. coli* isolates from the samples were selected and screened for its sensitivity or resistance to antibiotic agents as described by the standard procedures of Clinical Laboratory Standard Institute. *E. coli* was grown on Mueller-Hinton agar in the presence of antimicrobial impregnated filter paper disks. The presence or absence of bacterial growth around the disks gave an indirect measure of that antimicrobial agent or compound's ability to inhibit that organism. This measurement was then compared to the guide value provided by Clinical Laboratory Standards International (CLSI) for bacteria within the enterobacteriae group and thence classified as susceptible, intermediate or resistant (Plate 2).

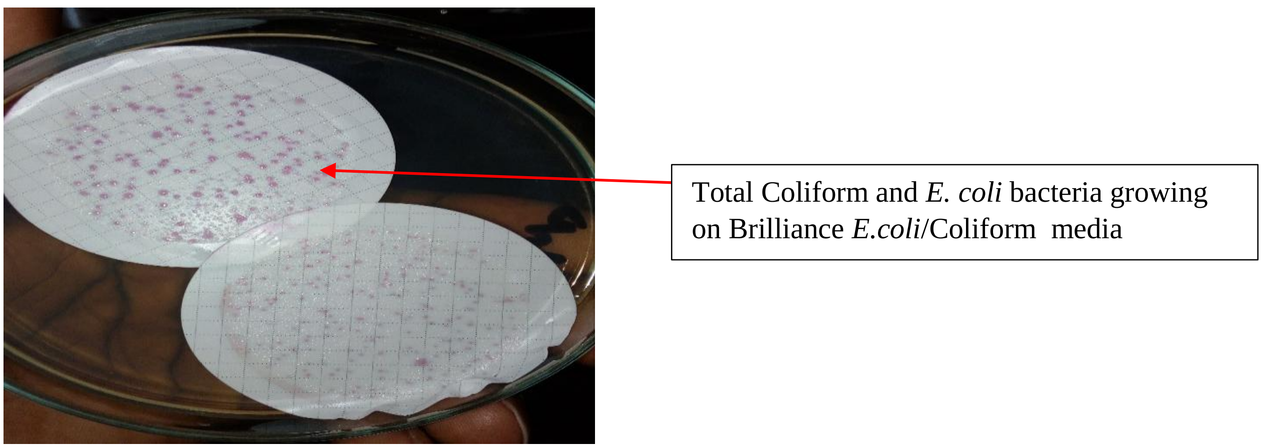

Plate 1: Bacteria growth on membrane filter

3.6 Data Management and Analysis

The bacterial load data was computed for descriptive statistics whiles physico-chemical concentrations were loaded and computed for descriptive statistics analysis, one-way t-test analysis with significance level set at $p < 0.05$. The GraphPad Prism (version 8.4.3) was the statistical tool used for all statistical analysis. Results from the data analysed were displayed in tables and bar graphs.

3.7 Human risk assessment methodologies

The health risk assessment was centred on exposure factors, the guidelines used in this study were extracted from the handbook of the United States Environmental Protection Agency (USEPA, 2009; USEPA 2011). Few exposure factors were modified to reflect the Ghanaian conditions. The chronic daily intake for carcinogenic and non-carcinogenic elements via ingestion was evaluated following equations (1) and (2)

$$\mathrm{CDI}_{C} = C \left[\frac{I_nR \ X \ E_f \ X \ E_xD_C}{BW \ X \ AT_C}\right] \qquad (1)$$

$$\mathrm{CDI}_{n-c} = C \left[\frac{I_nR \ X \ E_f \ X \ E_xD_{n-c}}{BW \ X \ AT_{n-c}}\right] \qquad (2)$$

CDIc = Chronic daily intake of carcinogenic element in water (mg/kg/day), CDIn-c = Average Chronic daily intake for non-carcinogen element in water (mg/kg/day), C = concentration of element in the water (mg/L), InR = Intake rate (L/day), Ef = Exposure frequency (350 days/year), ExDc = Exposure duration (carcinogen) (365 days), ExDn-c = Exposure duration (non-carcinogen) (365 days), BW = Body weight (kg), ATc = Average time (carcinogen) (days), and ATn-c = Averaging time (non-carcinogen) (days), ET = Exposure Time (h/day), CF = Unit conversion factor (L/cm3),

The Hazard Quotient (HQ) was computed using equations (3) and (4).

$$\text{Hazard Quotient (HQ)} = \left[\frac{CDIc}{RfD_{Oral}}\right] \qquad (3)$$

$$\text{Hazard Quotient (HQ)} = \left[\frac{CDIn-c}{RfD_{Oral}}\right] \qquad (4)$$

The Reference dose (RfDs) for oral toxicity used in the computation are as follows: Cd - 5.00E-04, Cu - 3.7E-02, Fe - 7.00E-01, Mn - 1.40E-01, and Zn - 3.00E-01 (mg/kg/day). HQ was evaluated as < 1 for harmful and < 1 for non-harmful.

The summation of the HQs presents the total potential health risk or Hazard Index (HI). The HI computation was applied using equation (5)

$$\text{HI} = \sum_{i=1}^{n}[HQ_{Cu} + HQ_{Cd} + HQ_{Zn} + HQ_{Mn} + HQ_{Fe}] \quad (5)$$

Cancer risk (CR) associated with the consumption of the water sources were computed following the formula (6) as proposed by USEPA (2009).

$$\text{Cancer risk (CR)} = CDI_{Oral}\ x\ \text{SF} \quad (6)$$

Cancer risk is presented by CR (mg/kg/day), CDI is the chronic daily intake (mg/kg/day), and SF is the slope factor of the carcinogen. The respective SF of the studied carcinogen, Cd is (0.380 mg/kg/day). The tolerable risk ranged from 10−6 to 10−4 (USEPA, 2009).

CHAPTER FOUR

4.0 RESULTS

4.1 Introduction

This chapter presents the findings on the microbial contaminants load enumerated, physical and chemical parameters, including the estimated chronic daily intake levels, hazard quotient and hazard index. The chapter also covers data on antibiotic susceptibility of *E. coli* isolates.

4.2 Bacterial Load and Prevalence of Hand-dug Wells and Boreholes

4.2.1 Bacterial load and prevalence of hand-dug wells

From Table 4.1, Total Coliform counts in HDW recorded load ranged from 0 – 3.85 x 10^4 cfu/ ml and had a mean value of 1.66 x 10^4 cfu/ml ± 1.60 x 104. Faecal Coliform counts ranged from 0 – 1.88 x 10^4 cfu/ml and had a mean count of 0.275 x 10^4 cfu/ml ± 0.27 x 10^4. Also, *E. coli* counts recorded a range of 0 – 1.69 x 10^4 cfu/ml with a mean value of 0.20 x 10^4 cfu/ml ± 0.55 x 10^4. Of the total number of wells sampled, 66% tested positive for Total and faecal Coliform whereas 44% tested positive for *E. coli*.

Table 4. 1 Bacterial counts and prevalence enumerated from hand-dug wells

Sample I.D.	Total coliform (cfu/1 ml)	Faecal coliform (cfu/1 ml)	*Escherichia coli* (cfu/1 ml)
Q. Elizabeth HDW	3.22 E+04	0.12 E+04	0
Banvim HDW	1.10 E+04	0.20 E+02	0.20 E+02
Womale	0	0	0
Dufaa	1.05 E+04	0.08 E+04	0.08 E+04
Janshegu	3.72 E+04	9	5
Choggu	2.00 E+04	1.88 E+04	1.69 E+04
Vittin top	0	0	0
Kammonayili	385	11	0
Gbanyamile	0	0	0
Minimum	0	0	0
Maximum	3.85 E+04	0.11 E+04	169
Mean±SD	166.00±160.23	27.55±27.00	20.44±55.78
Prevalence (%)	66.67	66.	1.09

Sources: Field data, 2021

*Prevalence = (number of sites with bacteria counts / total number of sites) x 100%

*Where E = Exponent

4.2.2 Bacterial load and prevalence of boreholes

From Table 4.2, the estimated Total Coliforms load ranged from 0 – 3.72 x 10^4 cfu/ml with a mean value of 0.66 x 10^4 cfu/ml ± 0.13 x 10^4. Faecal Coliform counts ranged from 0 – 0.36 x 10^4cfu/ml with a mean value of 0.66 x 104cf/ml ± 0.13 x 10^4. Also, the *E. coli* counts ranged from 0 – 0.05 x 10^4 cfu/ml with a mean counts of 0.01 x 10^4 ± 0.019 x 10^4 cfu/ml. Of the total boreholes sampled, 63.6%, 36.3% and 27.2% got tested for TC, FC and *E. coli*.

Table 4. 2 Bacterial counts and prevalence enumerated from boreholes

Site descript.	**Total coliform (cfu/1 ml)**	**Faecal coliform (cfu/1 ml)**	***Escherichia coli* (cfu/1 ml)**
Sognayili BH	2.12 $^{E+04}$	0	0
Choggu BH	0.06 $^{E+04}$	0.02 $^{E+04}$	0
1st November	0	0	0
Urban road area	0	0	0
Stadium area	0	0	0
SSNIT area	0.07 $^{E+04}$	0	0
Tua BH	0	0	0
Dr. Tamin area BH	0.11 $^{E+04}$	0	0
Dabokpa BH	0	0	0
Central BH	0.72 $^{E+04}$	0.12 $^{E+04}$	0.03 $^{E+04}$
Poly environ. area	3.72 $^{E+04}$	0.46 $^{E+04}$	0
GSA and WHO standard	0	0	0
Minimum	0	0	0
Maximum	372	46	5
Mean±SD	0.65 $^{E+04}$±119.77	0.0663 $^{E+04}$±13.95	0.109 $^{E+04}$±1.92
Prevalence (%)	63.63	36.36	27.27

Sources: Field data, 2021

*****Prevalence = (number of sites with bacteria counts / total number of sites) x 100%

*Where E = Exponent

4.3 Physical and Chemical Contaminants

4.3.1 Levels of pH of hand-dug wells

pH levels of hand-dug wells explored in the current study are shown in Figure 4.1. The mean pH level of hand-dug wells was approximately 7.47±0.54 pH units. The observed data ranged from 6.59 to 8.10 pH units. Dufaa and Womale recorded a minimum value of 6.59 pH units while Vittin top recorded the maximum pH reading of 8.10 pH units as shown in Figure 4.1.1. There was a significant variation in pH levels recorded for the various water samples from the nine communities explored in the current study.

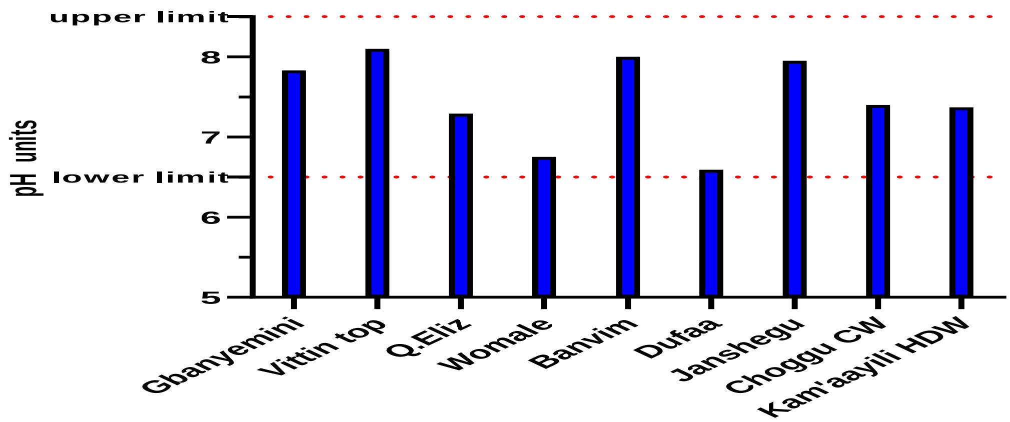

Figure 4. 1 pH levels of hand-dug wells

4.3.2 pH levels of boreholes

Figure 4.2 shows pH levels of boreholes explored in the nine communities. The mean pH level of 7.60±0.45 pH units was recorded for boreholes. Furthermore, the pH levels ranged from 7.10 – 8.47pH units. The lowest reading of 7.10 pH units was recorded for SSNIT and Stadium CW whereas the highest reading of about 8.47 pH unit was recorded for Vittin Top as shown in Figure 4.2.2.

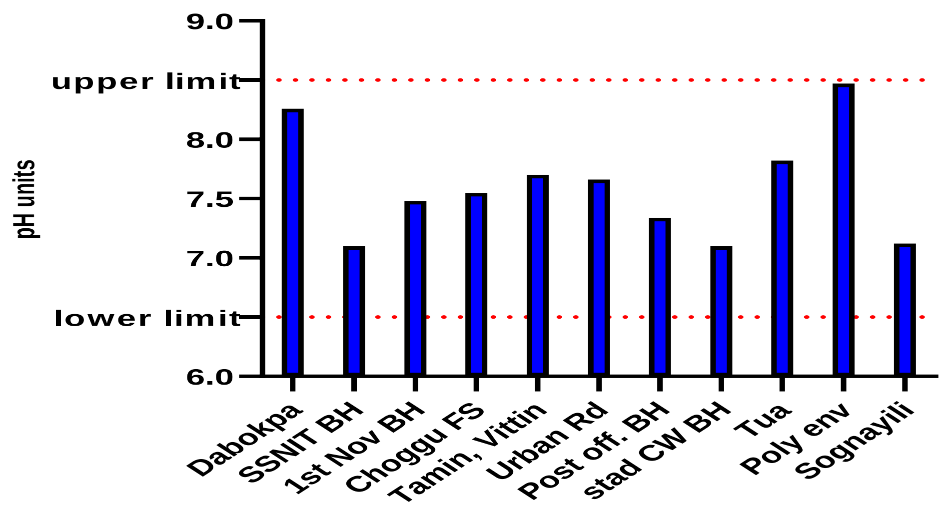

Figure 4. 2 pH levels of boreholes

4.4.3 Turbidity levels in hand-dug wells

Turbidity levels recorded for hand-dug wells are indicated in Figure 4.2.3. The mean turbidity level recorded for the various sentinel sites was approximately 56.56±66.33 NTU. The turbidity ranged from 3 – 183 NTU. Furthermore, the maximum and minimum levels occurred at Kammonaayili and Queen Elizabeth, respectively, as shown in Figure 4.1.3.

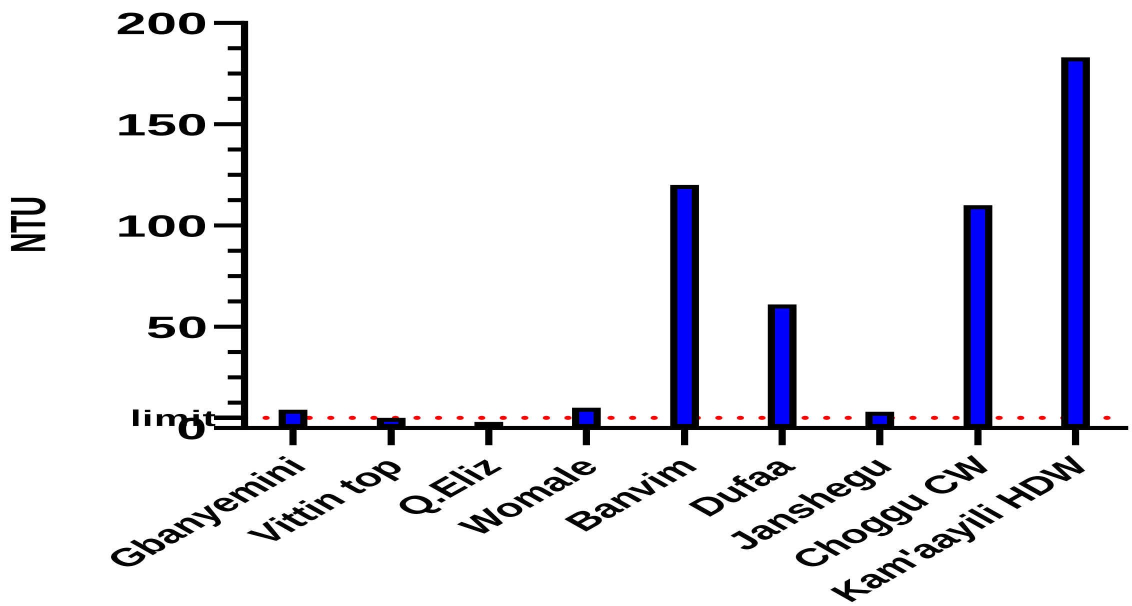

Figure 4. 3 Turbidity levels of hand-dug wells

4.4.4 Turbidity levels in borehole water

Figure 4.4 shows turbidity levels for water samples from the borehole samples which were explored. There was a mean turbidity level of 67.55±62.26 NTU and a range of 181.00 NTU. The minimum and maximum turbidity readings were one (1) NTU and 182 NTU, respectively.

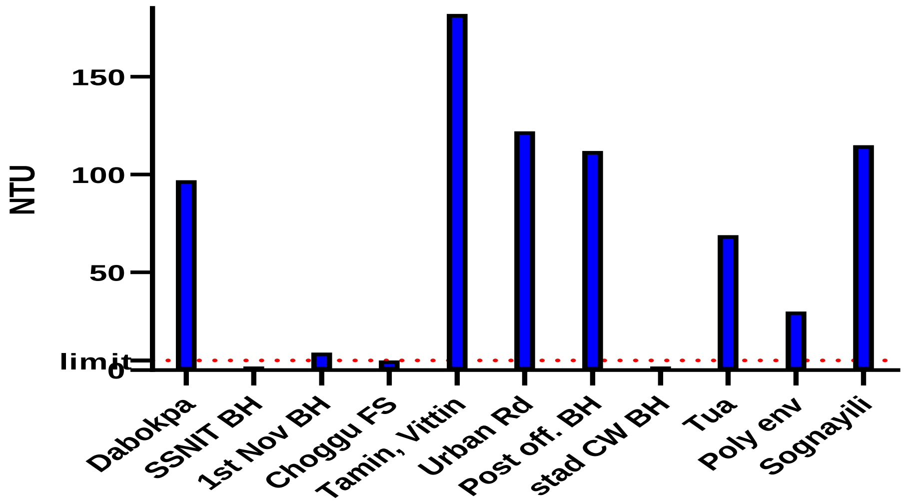

Figure 4. 4 Turbidity levels from boreholes

4.4.5 Conductivity levels in hand-dug well water

Figure 4.5 shows the conductivity levels of hand-dug well water samples studied. From the data, the mean value conductivity level was 281.63±185.9µS/cm. The data ranged from 57.94 to 628.00 µS/cm. The lowest and highest values occurred at Dufaa and Janshegu.

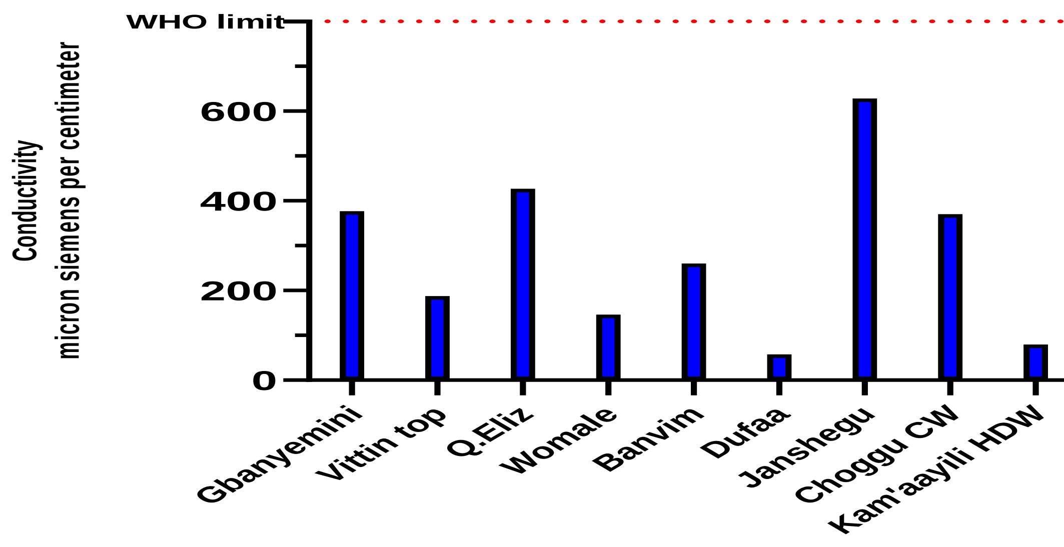

Figure 4. 5 Conductivity levels recorded from hand-dug wells

4.4.6 Conductivity levels of boreholes

The data on electrical conductivity levels of boreholes explored in the current study is shown in Figure 4.2.6. The conductivity data ranged from 36.58 and 2113 µS/cm. The mean conductivity value was approximately 298.73±609.7 µS/cm with the lowest and highest conductivity levels occurring at Sognayili and Dabokpa in Figure 4.1.6.

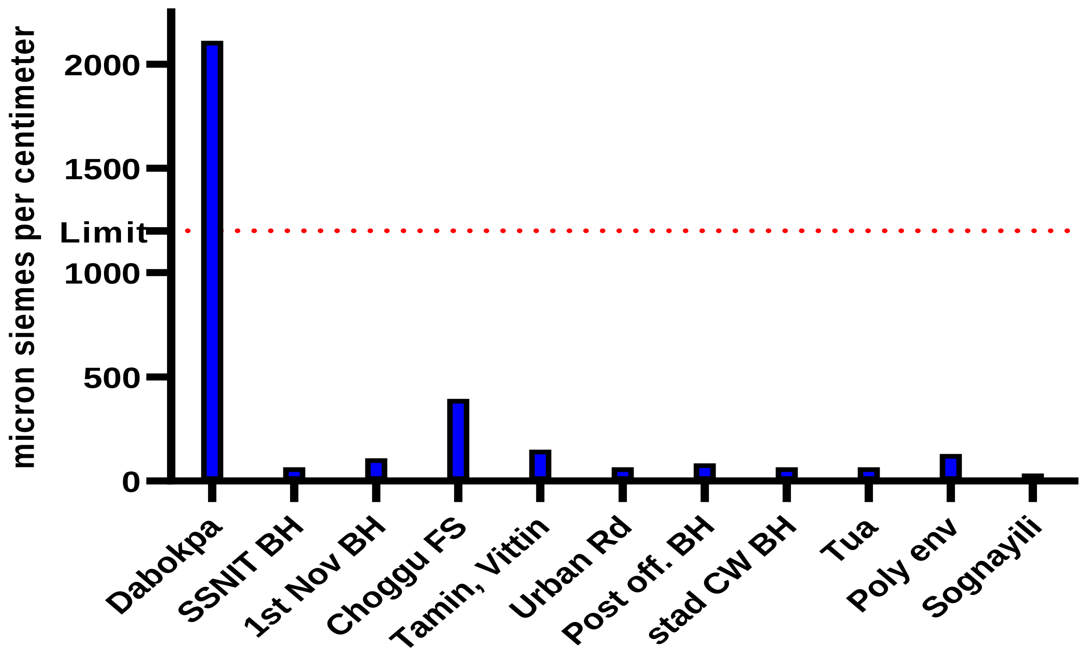

Figure 4. 6 Conductivity levels from boreholes

4.4.7 Concentration of iron (Fe) from hand-dug wells

The data on the concentration of iron (Fe) recorded from the hand-dug wells is indicated in Figure 4.2.7. The average Fe concentration for the wells was 0.222±0.307 mg/L. Furthermore, the concentration ranged from 0.001 – 1.001 mg/L. From Figure 4.2.7, the lowest and highest Fe concentration occurred at Gbanyemini and Choggu, respectively.

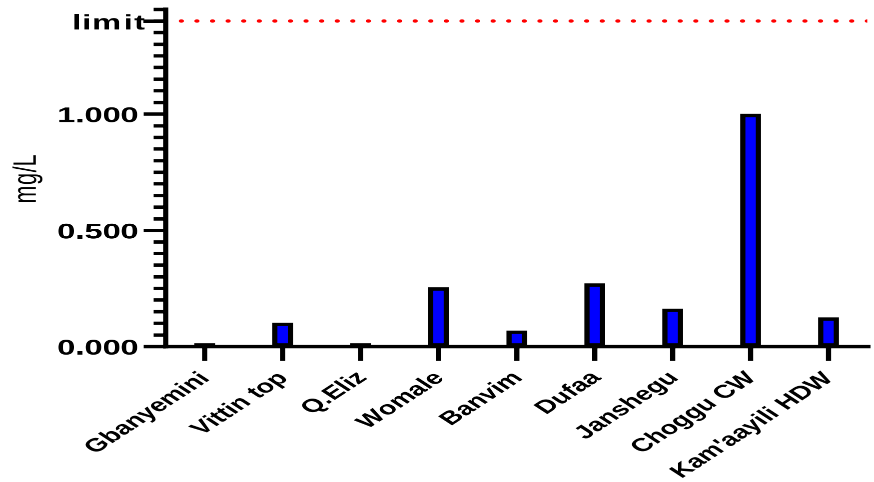

Figure 4. 7 Iron concentrations in sampled hand-dug wells

4.4.8 Iron concentration from boreholes

Figure 4.8 illustrates iron concentration from the investigated boreholes. The Fe data ranged from 0.001 to 10.456 mg/L. The mean Fe concentration was 1.624±3.295 mg/L. As shown in Figure 4.2.8, the minimum and maximum Fe concentrations were recorded at Sognayili and Tamin, respectively.

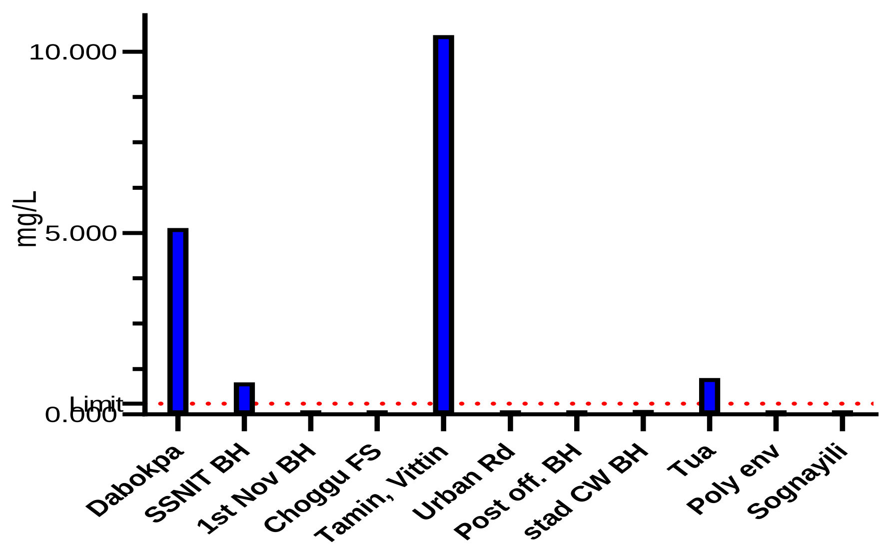

Figure 4. 8 Iron concentrations in boreholes

4.4.9 Manganese (Mn) and Zinc (Zn) concentration from hand-dug wells

Figure 4.2.9 illustrates manganese concentration recorded from hand-dug wells. The concentration ranged from 0.001 to 0.059 mg/L for Mn. Similarly, that of Zn also ranged from 0.001 to 0.154 mg/L. The average manganese and zinc concentration recorded were 0.0197±0.020 mg/L and 0.030±0.055 mg/L, respectively. The least and highest concentrations of Mn occurred at Gbanyemini, Choggu and Womale, respectively as shown in Figure 4.2.9.

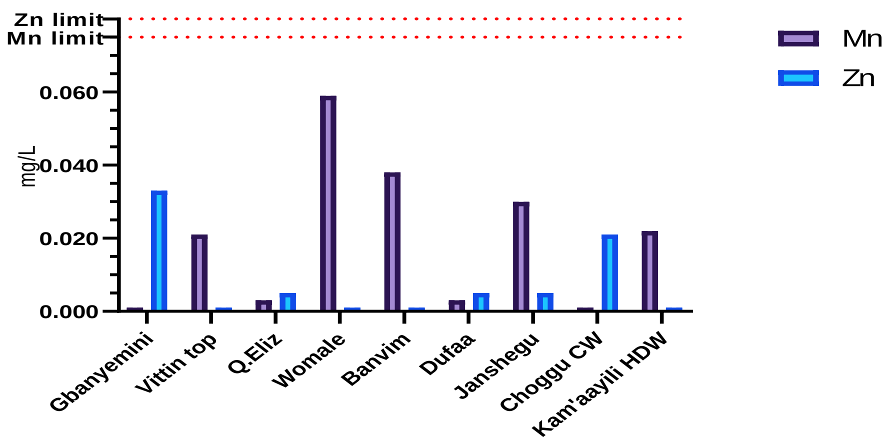

Figure 4. 9 Manganese concentration from hand-dug wells

4.4.10 Manganese (Mn) and Zinc (Zn) concentration from boreholes

Figure 4.2.10 illustrates the manganese concentration recorded from boreholes. The concentration ranged from 0.001 to 0.406 mg/L for Mn. Similarly, that of Zn also ranged 0.001 to 0.154 mg/L. The average manganese and zinc concentration recorded were 0.084±3.295 mg/L and 0.30±0.055 mg/L, respectively. The least and highest concentrations of Mn occurred at Gbanyemini, Choggu and Womale, respectively as shown in Figure 4.2.10. Zn highest concentration was recorded at Tamin, Vittins (Figure 4.2.10).

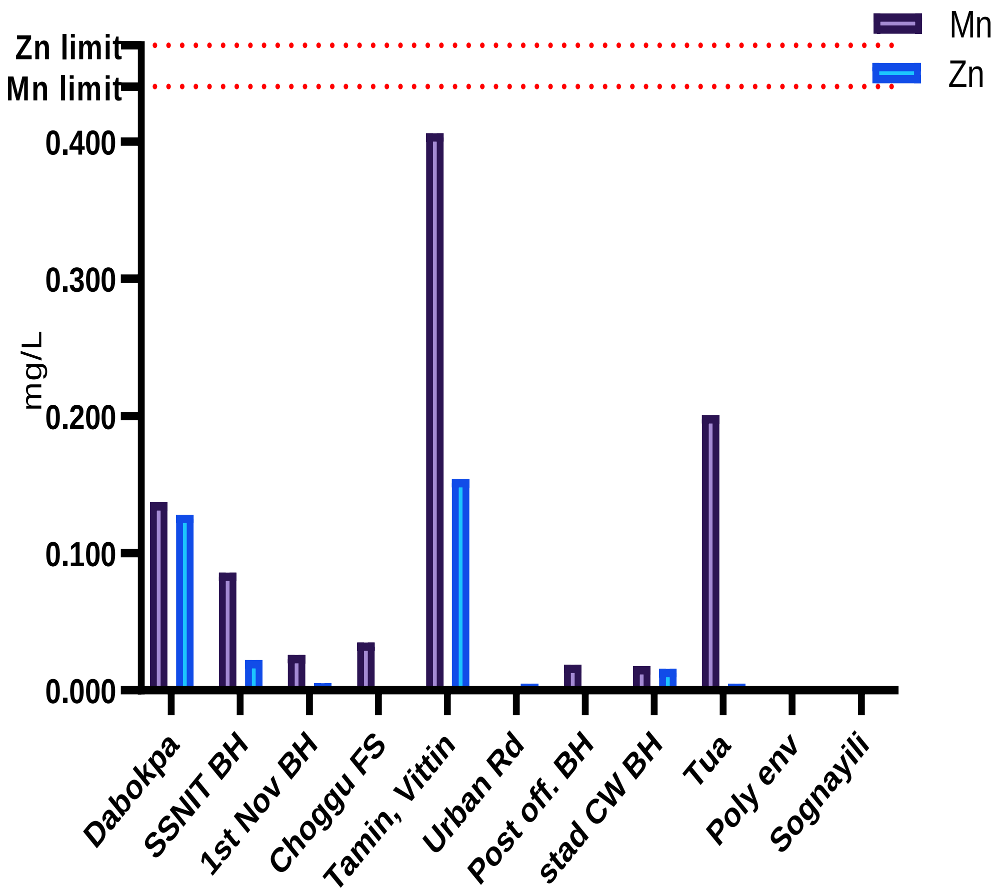

Figure 4. 10 Manganese concentration from boreholes.

4.4.11Concentration of Cadmium (Cd) and copper (Cu) from hand-dug wells

The concentration of cadmium (Cd) and copper (Cu) from hand-dug wells is illustrated in Figure 4.2.11. The mean concentration for cadmium and copper were 0.002 ± 0.003 mg/L and 0.019 ± 0.039 mg/L. Cadmium concentration ranged from 0.001 to 0.009 mg/L whereas copper concentration ranged from 0.001 – 0.136 mg/L. The highest concentration of Cd and Cu occurred at Queen Elizabeth and Choggu (Figure 4.2.11).

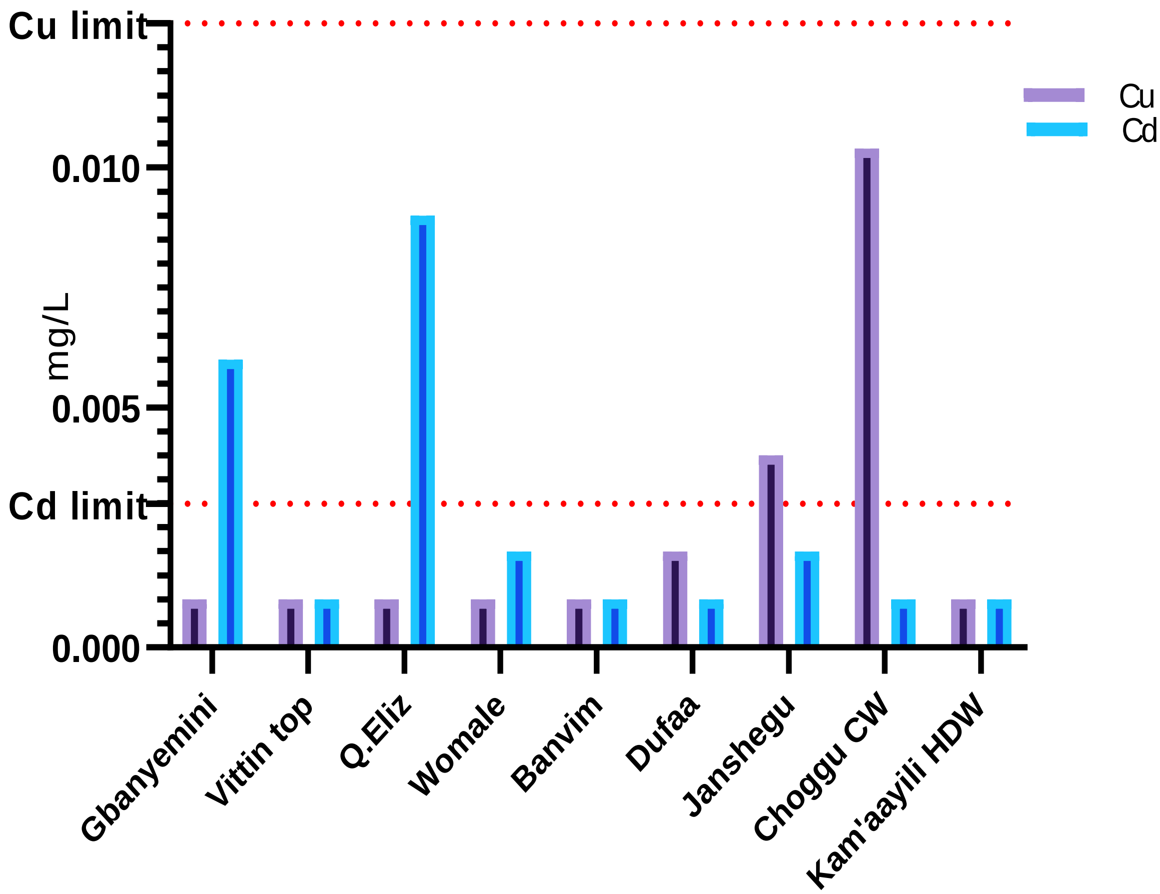

Figure 4. 11 Concentration of Cadmium and Copper from boreholes

Figure 4.2.12 shows the concentration of zinc and copper recorded for water samples from hand-dug wells. The average concentrations of Zn and Cu were approximately 0.008±0.011 and 0.003±0.003 mg/L, respectively. Furthermore, the range value of approximately 0.032 and 0.0088 were estimated for the hand-dug well samples. The minimum concentrations of zinc and copper were approximately 0.001 mg/L and about 0.001 mg/L, respectively. On the other hand, the maximum concentrations of zinc and copper recorded were 0.001 mg/L and 0.010 mg/L, respectively.

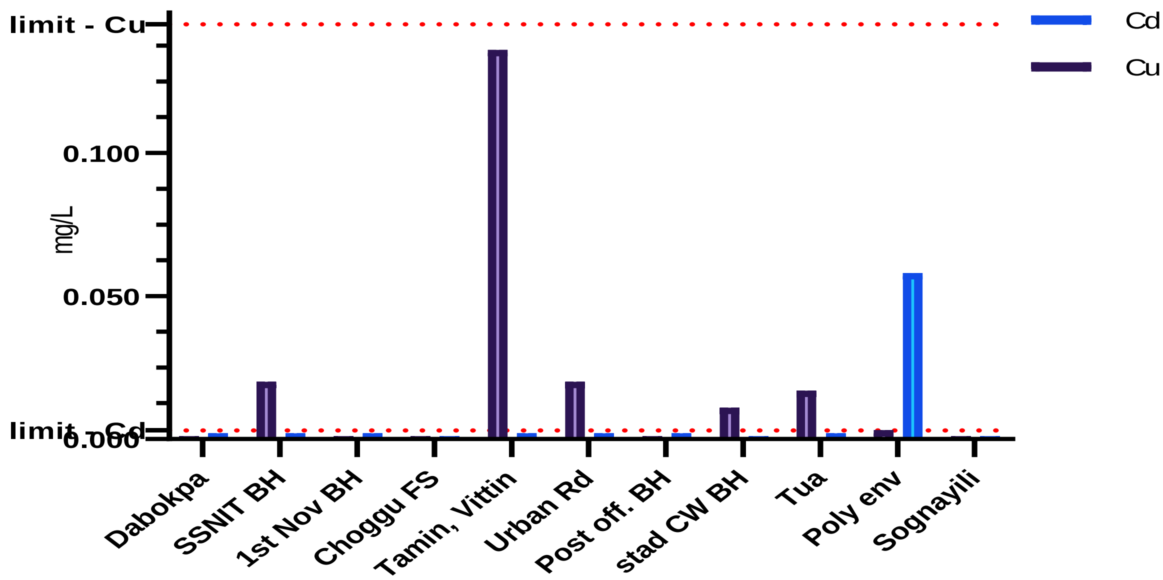

Figure 4. 12 Concentrations of Cadmium and Copper from hand-dug wells

4.5 One Sample T-Statistical Analysis for Hand-Dug Wells and Boreholes

4.5.1 T-test results for heavy metals from hand-dug wells

Table 4.1 shows t-test values for heavy metals concentrations from hand-dug wells. All other chemical elements except zinc generated *p* values less than 0.05 ($p<0.05$).

Table 4. 3 One sample T-test results for heavy metals from hand-dug well

Chemical Element/ One sample t-test	Cu	Fe	Mn	Zn	Cd
t, df	t=2.385, df=8	t=2.174, df=8	t=2.944, df=8	t=2.158, df=8	t=2.785, df=8
P value (two-tailed)	0.0442	0.0615	0.0186	0.063	0.0237
Significant (alpha=0.05)	Yes	No	Yes	No	Yes

*****t is test statistic, df is degree of freedom, p is probability

4.5.2 One-sample T-test results for heavy metals from boreholes

Table 4.1 shows t-test values for heavy metals concentrations from boreholes. Except for zinc, all other chemical elements generated p values less than 0.05 ($p<0.05$).

Table 4. 4 T-test results for heavy metals from boreholes

Chemical Element/ One sample t test	Cu	Fe	Mn	Zn	Cd
t, df	t=1.618, df=10	t=1.635, df=10	t=2.254, df=10	t=1.852, df=10	t=1.332, df=10
P value (two tailed)	0.1366	0.1332	0.0479	0.0938	0.2125
Significant (alpha=0.05)	No	No	Yes	No	No

*****t is test statistic, df is degree of freedom, *p* is probability

4.6 Chronic Daily Intake Levels, Hazard Quotient and Hazard Index Estimates for Hand-Dug Wells and Boreholes

4.6.1 Chronic daily intake levels, hazard quotient and hazard index estimates for hand-dug wells

Table 4.3 shows the estimated chronic daily intake (CDI) and hazard index (HI) of hand-dug well water users among adult users. CDI values for Cu and Zn ranged from 2.75^{E-04} to 1.05^{E-04} and 8.70^{E-04} to 1.05^{E-04}, respectively. Fe and Mn data ranged from 2.34^{E-02} to 1.05^{E-04}. HQ values for Cu and Zn ranged from 2.62^{E-03} to 2.73^{E-02} and 3.50^{E-04} to 1.18^{E-02}. Fe and Mn HQ values ranged from 1.50^{E-04} to 1.57^{E+00} and 7.50^{E-03} to 3.04^{E+00}, respectively. Lastly, HI ranged from 1.06^{E-02} to 5.02^{E+00}.

Table 4.4 relates to CDI, HQ and HI for HDW among infant users. CDI for Cu and Zn occurred within 1.28^{E-04} to 1.33^{E-03} and 6.39^{E-05} to 1.19^{E-03}, respectively. Fe and Mn values ranged from 1.28^{E-04} to 1.28^{E-01} and 1.28^{E-04} to 7.57^{E-03}, respectively. HQ for Cu and Zn ranged from 3.20^{E-03} to 3.32^{E-02} and 4.26^{E-04} to 1.44^{E-02}, respectively. Similarly, Fe and Mn values also ranged from 1.83^{E-04} to 1.83^{E-01} and 9.13^{E-03} to 5.41^{E-01}, respectively. Overall, HI values ranged from 2.69^{E-02} to 5.92^{E-01}.

4.6.2 Chronic daily intake levels, hazard quotient and hazard index estimates from boreholes

Table 4.4 shows computed chronic daily intake, hazard quotient and hazard index among adult users. The generated values for CDI ranged from 1.28^{E-04} to 1.73^{E-02} and 1.05^{E-04} to 1.62^{E-02} for Cu and Zn, respectively. Similarly, CDI values for Fe and Mn ranged from 1.05^{E-04} to 1.10^{E+00} and 1.05^{E-04} to 4.26^{E-02}, respectively. The HQ values, Cu and Zn were below 1.00E+00 whereas Fe and Mn generated a value beyond 1.00E+00 as detailed in Table 4.4. The estimated HI values were within 1.09^{E-02} to 5.02^{E+00}.

Table 4.4 shows infant users of borehole exposure levels, hazard quotient and hazard index. The computed CDI (Cu and Zn) ranged from 1.28^{E-04} to 1.73^{E-02} and 1.28^{E-04} to 1.97^{E-02}, respectively. CDI for Fe and Mn ranged from 1.28^{E-04} to 1.34^{E+00} and 1.28^{E-04} to 5.19^{E-02}, respectively. Regarding HQ, recorded data range for Cu and Zn ranged from 3.20^{E-03} to 3.32^{E-02} and 4.26^{E-04} to $1.19^{E+01}$for Fe and Mn. Overall, HI values ranged from 1.29^{E-02} to 6.12^{E+00}.

Table 4. 5 Exposure levels, hazard quotient and hazard index of adults to non-carcinogenic heavy metals from HDW

	Chronic daily intake (mg/kg/day)				Hazard Quotient				
Heavy metal (non-carcinogen) / ID	Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn	HI
Gbanyemini	1.05^{E-04}	1.05^{E-05}	1.05^{E-04}	3.54^{E-03}	2.62^{E-03}	1.50^{E-04}	1.50^{E-04}	1.18^{E-02}	2.21^{E-02}
Vittin top	1.36^{E-04}	1.08^{E-02}	2.17^{E-03}	3.36^{E-05}	3.41^{E-03}	1.54^{E-02}	2.56^{E-03}	4.55^{E-04}	1.74^{E-01}
Q.Eliz	1.36^{E-04}	1.05^{E-03}	3.15^{E-04}	5.25^{E-04}	1.28^{E-04}	1.28^{E-04}	3.84^{E-04}	1.75^{E-03}	2.92^{E-02}
Womale	1.36^{E-04}	2.68^{E-02}	6.22^{E-03}	1.36^{E-04}	1.28^{E-04}	3.26^{E-02}	7.54^{E-03}	4.55^{E-04}	4.86^{E-01}
Banvim	1.36^{E-04}	7.34^{E-03}	3.97^{E-03}	1.360^{E-04}	1.28^{E-04}	8.82^{E-03}	4.73^{E-03}	4.55^{E-04}	2.98^{E-01}
Dufaa	2.10^{E-04}	2.86^{E-02}	3.15^{E-04}	5.25^{E-04}	2.56^{E-04}	3.48^{E-02}	3.84^{E-04}	1.75^{E-03}	7.03^{E-02}
Janshegu	4.20^{E-04}	1.72^{E-02}	3.17^{E-03}	5.25^{E-04}	5.11^{E-04}	2.10^{E-02}	3.84^{E-04}	1.75^{E-03}	1.92^{E-01}
Choggu CW	1.09^{E-03}	1.05^{E-01}	1.05^{E-04}	2.20^{E-03}	1.28^{E-04}	1.28^{E-01}	1.28^{E-04}	3.50^{E-04}	1.87^{E-01}
Kammonnaayili	1.05^{E-04}	1.32^{E-02}	2.31^{E-03}	1.05^{E-04}	1.28^{E-04}	1.61^{E-02}	2.81^{E-03}	1.28^{E-04}	2.28^{E-01}
USEPA limit					1.00^{E+00}				

Table 4. 6 Exposure levels, hazard quotient and hazard index of infants to non-carcinogenic heavy metals from HDW

	Chronic daily intake (CD) (mg/kg/day)				**Hazard Quotient (HO)**				
Heavy metal (non-carcinogen)/ 1D	Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn	HI
Gbanyenmini	1.28^{E-04}	1.28^{E-04}	1.28^{E-04}	4.31^{E-03}	3.20^{E-03}	1.83^{E-04}	9.13^{E-03}	1.44^{E-02}	2.69^{E-02}
Vittin top	1.66^{E-04}	1.31^{E-02}	2.65^{E-03}	1.66^{E-04}	4.16^{E-03}	1.87^{E-02}	1.89^{E-01}	5.54^{E-04}	2.12^{E-01}
Q.Eiz	1.66^{E-04}	1.28^{E-03}	3.84^{E-04}	6.39^{E-04}	4.16^{E-03}	1.83^{E-03}	2.74^{E-02}	2.13^{E-03}	3.55^{E-02}
Womale	1.66^{E-04}	3.26^{E-02}	7.57^{E-03}	1.66^{E-04}	4.16^{E-03}	4.66^{E-02}	5.41^{E-01}	5.54^{E-04}	5.92^{E-01}
Banvim	1.66^{E-04}	8.94^{E-03}	4.83^{E-03}	1.66^{E-04}	4.16^{E-03}	1.28^{E-02}	3.45^{E-01}	5.54^{E-04}	3.63^{E-01}
Dufaa	2.56^{E-04}	3.48^{E-02}	3.84^{E-04}	6.39^{E-04}	6.39^{E-03}	4.97^{E-02}	2.74^{E-02}	2.13^{E-03}	8.56^{E-02}
Janshegu	5.11^{E-04}	2.10^{E-02}	3.86^{E-03}	6.39^{E-04}	1.28^{E-02}	3.00^{E-02}	2.76^{E-01}	2.13^{E-03}	3.21^{E-01}
Choggu CW	1.33^{E-03}	1.28^{E-01}	1.28^{E-04}	2.68^{E-03}	3.32^{E-02}	1.83^{E-01}	9.13^{E-03}	8.95^{E-03}	2.34^{E-01}
Kammonnaayili	1.28^{E-04}	1.61^{E-02}	2.81^{E-03}	1.28^{E-04}	3.20^{E-03}	2.30^{E-02}	2.01^{E-01}	4.26^{E-04}	2.28^{E-01}
USEPA Threshold					$<1^{E+00}$				

Table 4. 7 Exposure levels, hazard quotient and hazard index of adults to non-carcinogenic heavy metals from boreholes

	Chronic daily intake (CD) (mg/kg/day)				**Hazard Quotient (HQ)**				
Heavy metal (non-carcinogen)/ ID	Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn	HI
Dabokpa	1.36^{E-04}	4.00^{E-01}	1.44^{E-02}	1.35^{E-02}	3.41^{E-03}	7.71^{E-01}	1.03^{E+00}	4.49^{E-02}	1.85^{E+00}
SSNIT BH	2.10^{E-03}	9.26^{E-02}	9.03^{E-03}	2.33^{E-03}	5.25^{E-02}	1.32^{E-01}	6.45^{E-01}	7.77^{E-03}	8.38^{E-01}
Ist Nov BH	1.36^{E-04}	7.97^{E-03}	2.71^{E-03}	5.46^{E-04}	3.41^{E-03}	1.14^{E-02}	1.93^{E-01}	1.82^{E-03}	2.10^{E-01}
Choggu FS	1.36^{E-04}	8.81^{E-03}	3.64^{E-03}	1.36^{E-04}	3.41^{E-03}	1.26^{E-02}	2.60^{E-01}	4.55^{E-04}	2.77^{E-01}
Tamin, Vittin	1.42^{E-02}	1.10^{E+00}	4.26^{E-02}	1.62^{E-02}	3.56^{E-01}	1.57^{E+00}	3.04^{E+00}	5.40^{E-02}	5.02^{E+00}
Urban Rd	2.10^{E-03}	1.74^{E-03}	1.05^{E-04}	5.25^{E-04}	5.25^{E-02}	2.49^{E-03}	7.50^{E-03}	1.75^{E-03}	6.42^{E-02}
Post off. BH	1.36^{E-04}	2.36^{E-03}	1.95^{E-03}	1.36^{E-04}	3.41^{E-03}	3.37^{E-03}	1.39^{E-01}	4.55^{E-04}	1.47^{E-01}
stad CW BH	1.15^{E-03}	1.34^{E-02}	1.87^{E-03}	1.66^{E-03}	2.89^{E-02}	1.91^{E-02}	1.33^{E-01}	5.53^{E-03}	1.87^{E-01}
Tua	1.78^{E-03}	1.06^{E-01}	2.11^{E-02}	5.25^{E-04}	4.46^{E-02}	1.51^{E-01}	1.50^{E+00}	1.75^{E-03}	1.70^{E+00}
Poly enviro	3.36^{E-04}	5.45^{E-03}	2.10^{E-04}	1.05^{E-04}	8.40^{E-03}	7.78^{E-03}	1.50^{E-02}	3.50^{E-04}	3.15^{E-02}
Sognayili	1.05^{E-04}	1.05^{E-04}	1.05^{E-04}	1.05^{E-04}	2.62^{E-03}	1.50^{E-04}	7.50^{E-03}	3.50^{E-04}	1.06^{E-02}
USEPA Threshold					$<1^{E+00}$				

Table 4. 8 Exposure levels, hazard quotient and hazard index of infants to non-carcinogenic heavy metals from boreholes

	Chronic daily intake (CD) (mg/kg/day)				**Hazard Quotient (HO)**				
Heavy Metal (non-carcinogen) / 1D	Cu	Fe	Mn	Zn	Cu	Fe	Mn	Zn	HI
Dabokpa	1.66^{E-04}	6.57^{E-01}	1.75^{E-02}	1.64^{E-02}	4.16^{E-03}	9.39^{E-01}	1.25^{E+00}	5.47^{E-02}	2.25^{E+00}
SSNIT BH	2.56^{E-03}	1.13^{E-01}	1.10^{E-02}	2.84^{E-03}	6.39^{E-02}	1.61^{E-01}	7.85^{E-01}	9.46^{E-03}	1.02^{E+00}
Ist Nov BH	1.66^{E-04}	9.70^{E-03}	3.30^{E-03}	6.65^{E-04}	4.16^{E-03}	1.39^{E-02}	2.36^{E-01}	2.22^{E-03}	2.56^{E-01}
Choggu FS	1.66^{E-04}	1.07^{E-02}	4.44^{E-03}	1.66^{E-04}	4.16^{E-03}	1.53^{E-02}	3.17^{E-01}	5.54^{E-04}	3.37^{E-01}
Tamin, Vittin	1.73^{E-02}	1.34^{E+00}	5.19^{E-02}	1.97^{E-02}	4.33^{E-01}	1.91^{E+00}	3.71^{E+00}	6.58^{E-02}	6.12^{E+00}
Urban Rd	2.56^{E-03}	2.12^{E-03}	1.28^{E-04}	6.39^{E-04}	6.39^{E-04}	3.03^{E-03}	9.13^{E-03}	2.13^{E-03}	7.82^{E-02}
Post off. BH	1.66^{E-04}	2.88^{E-03}	2.38^{E-03}	1.66^{E-04}	4.16^{E-03}	4.11^{E-03}	1.70^{E-01}	5.54^{E-04}	1.79^{E-01}
stad CW BH	1.41^{E-03}	1.63^{E-02}	2.28^{E-03}	2.02^{E-03}	3.52^{E-02}	2.33^{E-02}	1.63^{E-01}	6.73^{E-03}	2.28^{E-01}
Tua	2.17^{E-03}	1.29^{E-01}	2.56^{E-02}	6.39^{E-04}	5.43^{E-02}	1.84^{E-01}	1.83^{E+00}	2.13^{E-03}	2.07^{E+00}
Poly environ	4.09^{E-04}	6.64^{E-03}	2.56^{E-04}	1.28^{E-04}	1.02^{E-02}	9.48^{E-03}	1.83^{E-02}	4.26^{E-04}	3.84^{E-02}
Sognayili	1.28^{E-04}	1.28^{E-04}	1.28^{E-04}	1.28^{E-04}	3.20^{E-03}	1.83^{E-04}	9.13^{E-03}	4.26^{E-04}	1.29^{E-02}
USEPA Threshold					$<1^{E+00}$				

4.6 Carcinogenic risk values of cadmium (Cd)

Table 4.7 represents cadmium's estimated carcinogenic risk at all studied sites. Generally, risk values ranged from 1.99^{E-05} to 3.71^{E-04} among adult users and 2.43^{E-05} to 4.52^{E-04} among infant users. For boreholes water, adult risk values ranged from 3.99^{E-05} to 2.31^{E-03} whereas with infants it ranged from 4.86^{E-05} to 2.82^{E-05} to 2.82^{E-03}.

Table 4. 9: Carcinogenic risk value of cadmium (Cd)

Element	Sampled site description	HDW		Sampled site description	BH	
		(Adults)	(Infants)		(Adults)	(Infants)
Cd	Gbanyemini	2.43^{E-04}	2.96^{E-04}	Dabokpa	7.98^{E-05}	9.72^{E-05}
	Vittin top	3.99^{E-05}	4.86^{E-05}	SSNIT	7.98^{E-05}	9.72^{E-05}
	Q. Eliz.	3.71^{E-04}	4.52^{E-04}	1 NOV	7.98^{E-05}	9.72^{E-05}
	Womale	7.98^{E-05}	9.72^{E-05}	Choggu FS	3.99^{E-05}	4.86^{E-05}
	Banvim	1.99^{E-05}	2.43^{E-05}	Tamin, Vittin	7.98^{E-05}	9.72^{E-05}
	Dufaa	1.99^{E-05}	2.43^{E-05}	Urban road	7.98^{E-05}	9.72^{E-05}
	Janashegu	7.98^{E-05}	9.72^{E-05}	Post Off	7.98^{E-05}	9.72^{E-05}
	Choggu	3.99^{E-05}	4.86^{E-05}	Stadium CW	3.99^{E-05}	4.86^{E-05}
	Kammonaayili	3.99^{E-05}	4.86^{E-05}	Tua	7.98^{E-05}	9.72^{E-05}
				Poly	2.31^{E-03}	2.82^{E-03}
				Sognayili	3.99^{E-05}	4.86^{E-05}
Min		1.99^{E-05}	2.43^{E-05}		3.99^{E-05}	4.86^{E-05}
Max		3.71^{E-04}	4.52^{E-04}		2.31^{E-03}	2.82^{E-03}
USEPA tolerable range		$1.00^{E-06} – 1.00^{E-04}$			$1.00^{E-06} – 1.00^{E-04}$	

4.7 Antibiotic Susceptibility Test (AST)

4.7.1 Antibiotic susceptibility test of *E. coli* isolates from hand-dug wells and boreholes

Table 4.8 presents a summarises the antibiotic susceptibility test carried out on *E. coli* isolated from hand-dug wells and boreholes. Approximately, 62.5% of antibiotic agents (Nitrofurantoin, Ceftazidime, Gentamicin, Augmentin and Cefxime) tested were resisted by *E. coli* isolates. 50% of antimicrobials (Ciprofloxacin, Nitrofurantoin, Gentamicin and Ofloxacin) showed that *E. coli* was susceptible to them.

Table 4. 10 Antimicrobial agents and expressed responses

No.	**Antimicrobial Agent**		**(n=4)** Sensitive	Intermediate	resistant
1	CRR	Ciprofloxacin	4 (100%)	0 (0%)	0 (0%)
2	NIT	Nitrofurantoin	2 (50%)	0 (0%)	2 (50%)
3	CAZ	Ceftazidime	0 (0%)	0 (0%)	4 (100%)
4	CRX	Cefuroxime	0 (0%)	0 (0%)	4 (100%)
5	GEN	Gentamicin	3 (75%)	0 (0%)	1 (25%)
6	OFL	Ofloxacin	4 (100%)	0 (0%)	0 (0%)
7	AUG	Augmentin	0 (0%)	0 (0%)	4 (100%)
8	CXM	Cefixime	0 (0%)	0 (0%)	4 (100%)

Footnote: one study site did not test positive for a confirmatory test hence four isolates being the total sites subjected to antibiotic susceptibility tests.

CHAPTER FIVE

DISCUSSION

5.1 Bacteriological Analysis of Hand-Dug Wells and Boreholes

5.1.1 Total coliform (TC)

In this current study, the mean counts recorded for total coliform were 1.66^{E+02}/100 ml and 0.65^{E+02}/100 ml for hand-dug wells and boreholes, respectively (Table 4.5). These values exceed the GSA and WHO acceptable limit for potable use. The proportion of samples that got tested positive to total coliform were 66.7% and 63.6% for hand-dug wells and boreholes, respectively (Table 4.5). The data gathered was fairly similar to Bowan, (2022), Pesewu et al., (2015), and Nkansah et al., (2010) water quality studies in Ashanti, Greater Accra and Savannah regions, respectively. The enumeration of total coliform, probably, can be linked to unclean bowls and buckets in the water drawing especially among HDW users. Relatively, the long age of some HDWs may have influenced the coliform bacterial acceptability of the water resource. It can be inferred that, the presence of Total Coliform indicates the likely presence of other disease causative organisms (Alfred & Prosper, 2014). Consumers are at risk of developing gastro-intestinal illnesses especially with immune-compromised individuals and infants (Bekoe et al., 2021; Nkansah et al., 2010).

5.1.2 Faecal coliform (FC)

In this current study, mean Faecal Coliform counts recorded were 0.2755^{E+02}/100 ml and 0.0663E+02/100 ml for hand-dug wells and boreholes (Table 4.4), respectively. Compared with a GES and WHO standard this suggests that the water is bacteriologically unsafe for human ingestion.

This observation matches a similar study by Kadyampakeni et al., (2018) conducted in Northern Ghana. Furthermore, the results of the current study show that the proportion of samples that tested positive to faecal coliform for hand-dug wells and boreholes were approximately 66.7% and 36.3% respectively. This indicates that, hand-dug wells posed relatively higher risk of faecal contamination than boreholes. A possible contributory to the high faecal coliform counts in hand-dug wells was the relatively high turbidity levels that often shield bacteria. Additionally, anecdotal evidence from the owners revealed that disinfection was seldomly conducted on the water resources. Furthermore, it was deduced that, much of the hand-dug wells were shallow in terms of depth thus influencing the recharged water.

5.1.3 *Escherichia coli* (*E. coli*)

The results of the current study showed that *E. coli* mean counts recorded were 0.2044^{E+02}/100 ml for the hand-dug wells (Table 4.4) and 0.0019^{E+02}/100 ml (Table 4.5), respectively. The mean counts exceeded the GSA and WHO guideline indicating the water as being bacteriologically unsafe for drinking. This concur with some previous studies (Dzodzomenyo et al., 2022 and Odonkor & Mahami, 2020) conducted in the Northern and Greater Accra regions. The high counts of this bacterium at Choggu CW is attributable to the aging hand-dug well, shallow depth, short well wall and unhygienic surrounding. Field observation of the Choggu hand-dug well sides with the assertion that there was a likelihood of poor construction of the well. The proportion of samples that tested positive for *E. coli* (table 4.4 and table 4.5) was 44.4% for hand-dug wells and 27.2% for boreholes. Faecal-indicator bacteria, *E. coli*, is an indicator of sanitary condition, whose presence relays a recent contamination of the water (GSS, 2019; Nabeela et al., 2014).

5.2 Physico-chemical contaminants in Hand-dug wells and boreholes

5.2.1 pH

The current research findings revealed that the mean pH values were 7.57±0.54 and 7.60±0.45 pH units (Fig.4.3) for hand-dug wells (HDW) and boreholes (BH). The recorded pH level indicated slight alkalinity, hence considered ideal as it fell within the GSA and WHO acceptable range for potable use (WHO, 2017; GSA, 2015). This observation was similar to other groundwater quality studies by Appiah et al., (2021) and Duodu, (2014) in Southern Ghana. On the contrary, this current study mean pH range did not concur with Gyampo et al., (2014). The observed variation of pH in the groundwater may be attributed to the differences in the geological materials and hydrochemistry of the groundwater.

5.2.2 Turbidity

The current research revealed that the mean turbidity levels generated were 56.55±66.33 and 67.54±62.26 NTU for HDW and BH, respectively. According to the GSA and WHO guide values, safe water consumption is regcognized as search a levels 5 below NU. Comparing the studied values with the ideal value, the samples were adjudged to be unsafe for potable use. This observation contracts other related studies by Anim-Gyampo et al., (2022) and Anim-Gyampo et al., (2018) on groundwater in the Bawku and Ahafo-Ano districts, in the Upper East and Ashanti region. Plausible reasons for the high values can be attributable to atmospheric particulate matter deposition on hand-dug wells as against boreholes, which are enclosed. In addition, the side walls of the aged hand-dug wells were decaying and weathering into the water impairing the quality. High turbidity levels leads to increasing costs and risks for drinking water production especially among commercial operators (Kritzberg et al., 2020).

From the current research, an estimated 77% and 72% of HDW and BH did not record safe levels for turbidity. Although there is no known health effect, high turbidity values render such waters aesthetically unacceptable to users and negatively influence the recreational use of such water.

5.2.3 Conductivity

Results of the current study showed that the mean conductivity levels were approximately 281.63±185.91 μS/cm and 298.73±609.7 μS/cm for HDW and BH, respectively. All measured levels conformed to the GSA and WHO recommended limit for potable use (Fig. 4.5) except for the Dabokpa borehole (WHO, 2017; GSA, 2015). The current research results show that there were statistically significants differences between the conductivity levels for the water sample for the various scentinous site. The observed conductivity data for the hand-dug wells differed slightly compared with the results of the studies conducted by Akoto et al., (2019) since sites vary widely spatially per thorough examination. Similarly, conductivity values recorded for borehole water samples from the current study sites did not concur with that of Akoto et al., (2019) and Anim-Gyampo et al., (2014).

5.3 Heavy Metals

5.3.1 Iron (Fe)

The results of the current study as shown in Figures 4.7 and 4.8 showed that the average Fe concentration explored from data gathered computed was 0.222±0.307 mg/L for hand-dug wells value and 1.260±3.295 mg/L for boreholes. The average concentration exceeded the GSA and WHO acceptable limit for drinking purposes (0.3 mg/L).

This observation agrees with a study in Northern Ghana by Kadyampakeni et al., (2018) and Asare-Donkor et al., (2015) in the Obuasi enclave.

The results also showed that Fe concentrations gathered were statistically insignificant between the various studied sites (Table 4.3). Plausible reasons for Fe in groundwater systems can be attributed to hand-dug well and borehole depth, geological formation and pH levels as they are the primary triggers for Fe and Mn dissolution. Fe is an essential dietary necessity but excessive concentration can lead to gastrointestinal upset, iron toxicity and organ damage (Grazuleviciene et al., 2009; WHO, 2003). Other implications of elevated iron concentration are stains in laundry, cooking utensils and objectionable tastes to foods (WHO, 2003).

5.3.2 Manganese (Mn)

The results of the current research work showed that mean Mn concentration were 0.019±0.020 and 0.084±0.124 mg/L for hand-dug well and boreholes, respectively. Mn concentration for the boreholes exceeded the permissible limit and hence did not concur with similar groundwater quality studies by Boateng et al., (2015) conducted in the Ejisu environs. Ambient redox condition is the principal control of magnese concentartions under neutral pH. The aqueous chemistry of manganese is similar to that of iron. Soluble manganese in groundwater, released from minerals, is usually in a more reduced form (Mn^{2+}). As a result, much higher concentrations can be expected in anaerobic groundwater as dissolved oxygen in groundwater tend to decrease with well depth, influencing anaerobic conditions and hence elevating Mn concentration.

However, the above justification correlates with anecdotal evidence on boreholes depth by some owners of the boreholes. Alternatively, manganese is also an essential trace element for plants and animals (Addo et al., 2011)

5.3.3 Copper (Cu)

The mean Cu concentration were approximately 0.002±0.003 and 0.019±0.039 mg/L for HDW and BH, respectively. Cu concentration detected was below the GSA and WHO permissible limit of 2.00 mg/L. These concentrations were equivalent to the study of Appiah et al., 2021but contrast to that of Gyamfi et al., 2012. In humans, some amount of Cu is required to metabolize and synthesize of haemoglobin, myoglobin and several enzymes. Moreover, the Cu concentration observed in the study is likely to pose no risk of neurological complications, hypertension, liver and kidney problems (Krishna & Govil, 2004).

5.3.4 Zinc (Zn)

The current study showed that Zinc mean concentration for hand-dug wells and boreholes were approximately 0.008±0.011 and 0.030±0.055 mg/L. The observed data were within the GSA and WHO acceptable range for Zn element for potable use. Zn concentration observed in the current study was consistent with those of Akoto et al., 2019 and Anim-Gyampo et al., 2019. From this study, there were statistically insignificant values between zinc concentrations for the water samples at the various sentinel sites (Tables 4.3 and 4.4). Zinc is an essential growth element for plants and animals but prolonged consumption at elevated levels pose toxic effects such as anaemia, nausea, pancreas damage and decrease levels of high density lipoprotein (HDL) cholesterol (ATSDR, 2005).

5.3.5 Cadmium (Cd)

From the study, mean Cd concentrations were approximately 0.002±0.003 and about 0.006±0.016 mg/L for hand-dug wells and boreholes, respectively. These concentrations did not exceed the GSA and WHO guide value. The recorded concentrations with boreholes were consistent with a study in Obuasi by Akoto et al., (2019) but incomparable with Cobbina et al., (2013) which was conducted in Konongo-Odumasi. From the study, there were statistically significance (p value < 0.05) for Cd concentration from hand-dug well water (Table 4.3). The human exposure to higher concentration of Cd may cause acute health effect such as kidney damage (ATSDR, 2015).

5.4 Health Risk Assessment

Health risk assessment is estimating the health effects of a exposure to carcinogenic and non-carcinogenic chemicals (USEPA, 2001). The process encompasses four iterative steps, hazard identification, exposure assessment, dose-response assessment and risk characterization (USEPA, 2001). Conventionally, the parameter approach has been the technique of predicting health outcomes, especially concerning use water. This involves using different parameters (chemicals or microorganisms), analyzing their concentration or bacterial load separately and comparing the outcome with a reference or guideline value (USEPA, 1999).

5.4.1 Hazard identification

In this study, Fe, Mn, Zn, and Cd were identified as possible chemical hazards in groundwater systems. Similar studies and literature reviews including Mensah et al., (2022), Anim-Gyampo et al., (2019), Asare-Donkor et al., (2015) and Cobbina et al.,

(2011) equally emphasized a broader array of chemical contaminants including the studied heavy metals.

The prolonged farming in some of the study areas and changes in land-use for other areas were identified as few activities that influenced heavy metals/chemical elements considered in this research. Also, some of these areas have rapidly been converted to residential areas, warehouses and open dump sites (Mensah et al., 2022;Awotwi et al., 2015).

5.4.2 Exposure assessment

The research computed the chronic daily intake (CDI) of Fe, Mn, Zn, Cu and Cd orally ingested from the hand-dug well and borehole water in the different suburbs of Tamale. Expressions for exposure were obtained from the United States Environmental Protection Agency (USEPA) Risk Assessment Guidance for Superfund (RAGS) methodology (USEPA, 2009).

This research considered oral ingestion as the exposure route or pathway to assess how this route influences user risk. In contrast to other exposure routes (dermal contact and inhalation), oral ingestion poses the highest exposure. The volume of water consumed was set at 2.2 litres per day for adults and 1.8 litres for children (Anim-Gyampo et al., 2019; GSS, 2019). Exposure frequency (EF) is the frequency with which the exposure occurs and usually expressed in days per year (Asare-Donkor et al., 2016). Exposure duration (ED) denotes the average number of times in years the user is exposed to the contaminant being evaluated (Asare-Donkor et al., 2016).

Bodyweight denotes the weight of the user. 58.6 and 13.5 kg were applied to adults and children respectively as assessed during the 2000 national population and housing census and literature (Cobbina et al., 2013: GSS, 2012). The number of days the human user lives or populate's average lives span defines the averaging time (days). However, the slight difference in this assessment is with genotoxic carcinogens; exposure is compared with the dose corresponding with livetime cancer risk of 10^{-5}, the agreed "acceptable risk" (USEPA, 2022).

5.5 Chronic Daily Intake (CDI)

5.5.1 Chronic daily intake (CDI) – Hand-dug wells

From the study, the computed average chronic daily intake (exposure) values for all non-carcinogenic metals from hand-dug wells occurred within 5.20^{E-05} to 2.92^{E-04}. Adult users on average consumed the chemical elements in a decreasing order of magnitude; Mn, Fe, Zn and Cu. This range was consistent with a related study of Anim-Gyampo et al., (2019) conducted in Northern Ghana. Similarly, Infant users' consumption occurred in decreasing order of magnitude: Fe, Zn, Mn and Cu.

5.5.2 Chronic daily intake (CDI) - Boreholes

Throughout the study, mean CDI data generated from boreholes occurred within 5.73E-04 to 1.1E-03. Per the study, adult consumers ingested Fe, Cu, Zn and Mn (arranged in decreasing order of magnitude). In addition, infants recorded consumption in the decreasing order of magnitude; Fe, Mn, Zn and Cu (Table 4.2). The detection of Fe as the lead or widely ingested element among infant and adult users infers with Tay et al., (2019).

5.6 Hazard Quotient (HQ) and Hazard Index (HI)

5.6.1 Hazard quotient and hazard index of Hand-dug wells

From the current research, data collected and computed in Tables 4.5 and 4.6 show the estimated hazard quotient. Per the findings, Cu, Fe, Mn and Zn generated values were within the acceptable range of less than one (<1) (USEPA, 2022). Concerning infant users, the same was observed (<1). More so, the hazard index values computed had levels below one (1) indicating no or little potential non-carcinogenic effects on users across the studied pathway and multiple chemical elements.

5.6.2 Hazard quotient and hazard index of boreholes

With reference to Hazard Quotient levels and Hazard index from borehole water as shown in Table 4.3 and Table 4.4, all except for Fe and Mn exceeded the regulatory limit of less than one (<1) for both infant and adult users. Subsequently, Hazard Index values generated were less than one (<1) except for three (3) study sites in the case of the infant users. This observation affirms that infants at this stage, might have not fully developed internal organs to assimilate or retain these elements as compared to adults (Cobbina et al., 2013).

5.7 Carcinogenic Risk (CR)

5.7.1 Carcinogenic risk with hand-dug wells

From the data analysed in this study, carcinogenic element (Cd) concentration was applied to compute CR of infants and adults. The average CR for infants and adults were 2.15E-03 and 6.05E-04 for HDW and BH, respectively. Although infant CR value occurred within the USEPA acceptable range of 1E-06 to 1E-04, that of adult users did not. This implies that the likelihood exists for a user of developing carcinogenic effects over the lifetime of exposure. Further, this CR value indicates that two (2) deaths out of one thousand (1,000) infant population are likely. The computed data concur with a similar study in southern Ghana by Hadzi and Kofi, (2015).

5.7.2 Carcinogenic risk with boreholes

Also with boreholes, Table 4.7 shows computed CR values for both adult and infant users. The average carcinogenic risk for adults and infants were 5.49E-03 and 1.55E-03, respectively. These values fell outside the USEPA acceptable range of 1E-06 – 1E-04, posing a carcinogenic threat to users over a lifetime. The estimated CR value indicates the likelihood of five (5) deaths occurring in one thousand (1,000) adult population. This finding contrast similar health risk study by Liu & Ma, (2020).

5.8 Antibiotic Susceptibility Test

5.8.1 Antibiotic susceptibility test of hand-dug wells and boreholes

In this study, *E. coli* isolated from hand-dug wells and boreholes (Poly area BH, 1st November BH, Banvim CP HDW and Junshegu HDW) showed 100% resistance (Table 4.6) to the following antimicrobials: Ceftazidime, Cefuroxime, Augmentin and Cefixime. Similarly, two antimicrobials exhibited 100% susceptibility outcomes; Ciproflxacin and Ofloxacin. This observation concurs with some previous studies including Donkor et al., (2019) and Lutterodt et al., (2014) which also asserted Ciprofloxacin as an effective antibiotic regularly assessed and used in caregiving facilities. This observation is further stressed by another earlier study conducted by Ajibola et al., (2018) which reported that many people with diarrhoea and typhoid self-medicate with Ciprofloxacin. The implication of *E. coli* showing resistance suggests that a likely infection from the *E. coli* bacteria may not be treatable using Cefuroxime and Gentamicin.

CHAPTER SIX

6.0 SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of Findings

The results of the current study showed that the prevalence of total coliforms and faecal coliforms was 66.67% while that of *E. coli* was 44.44%. Regarding boreholes, the prevalence of total and faecal coliforms and *E. coli* was 63.63%, 36.36% and 27.27%. This implied that more than half of the samples were contaminated with total coliforms. Concerning the levels and concentrations of physico-chemical parameters (contaminants), turbidity, Fe, Mn and Cd had 22.2%, 11.1%, 44.4% and 22.2% of samples fall within the stipulated guide values. The pH, conductivity, Zn, and Cu of all hand-dug well samples met the required standards. On borehole water samples, 77.8%, 27.27%, 9.09% and 9.09% adhered to turbidity, iron, manganese and cadmium respectively. The other parameters: pH, conductivity, Cu, and Zn recorded 100% compliance with the GSA and WHO standards. Fe and Zn concentrations from the boreholes and hand-dug wells water samples were statistically insignificant (p value > 0.05).

Regarding hand-dug well water, computed Hazard quotient for Cu, Fe, Mn and Zn were less than one (1) for adults and infants indicating little or no potential non-carcinogenic effect or threat. Likewise, non-carcinogenic elements (Cu, Fe, Mn and Zn) investigated in boreholes generated Hazard quotient values less than one (1) except for Mn (for adults). Among infant users, HQ values occurred within the threshold range except for Fe and Mn (Table 4.4).

Concerning computed CDI, values were within the ranges of 10^{-2} to 10^{-5} for all studied non-carcinogenic elements except for infant users of borehole at Tamin, Vittin (Table 4.4). Fe from boreholes was the element widely absorbed by consumers. Carcinogenic risk (CR) from HDW and BH water sources fell within the ranges of 10-2 to 10+1 implying relatively high risk for adults. On the contrary, infants computed CR fell within the ranges of 10^{-7} to 10^{-5} implying a relatively lowered risk for infant consumers.

6.2 Conclusion

Based on the results of the current study, it was concluded that:

- A considerable proportion of the hand-dug wells (>44%) and boreholes (<22%) were bacteriologically unsafe for potable use.
- The average turbidity levels exceeded the GSA and WHO guide values (>70% of HDW and BH) indicating that most samples were unsafe for potable use.
- The Iron and Manganese concentrations in boreholes were revealed to be the most widely occurring chemical elements.
- The Hazard Quotient and Hazard Index levels exceeded the USEPA acceptable range.
- *E. coli* isolates were susceptible to Ciprofloxacin, Gentamicin and Ofloxacin. Thus, these antimicrobials may be useful in treating possible *E. coli* infection resulting from the studied water sources.

6.3 Recommendations

As a way to maintain the health of the public and lower the carcinogenic and non-carcinogenic health risks, there is a need to:

1. Periodically conduct disinfection on groundwater sources, especially places offering vending services, and ensure the regular conduct of comprehensive bacteriological and physico-chemical analysis. For this, this study proposes it to be executed by appropriate technical experts such as the Food and Drugs Authority.
2. The study advises groundwater sources recording elevated physico-chemical levels and concentrations over a period to be subjected to advance water treatment especially with vended water points.
3. Regulatory agencies should enforce the use of rightful skilled labour and proper construction materials in developing hand-dug wells and drilling or development of boreholes.

Further research

Further research work on this current study should encompass the following:

- A study on other pathogenic bacteria and their antibiotic susceptibility profiles.
- A quantitative microbial risk assessment to reveal risks associated with ingesting microbial contaminated water from the study area.
- Further studies on bacterial water quality should complement culture-based and molecular techniques in tandem to generate additional information of the antimicrobial resistance like the resistance genes of bacteria, *E. coli* and their sub-types in the environmental matrix.

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APPENDIX ONE

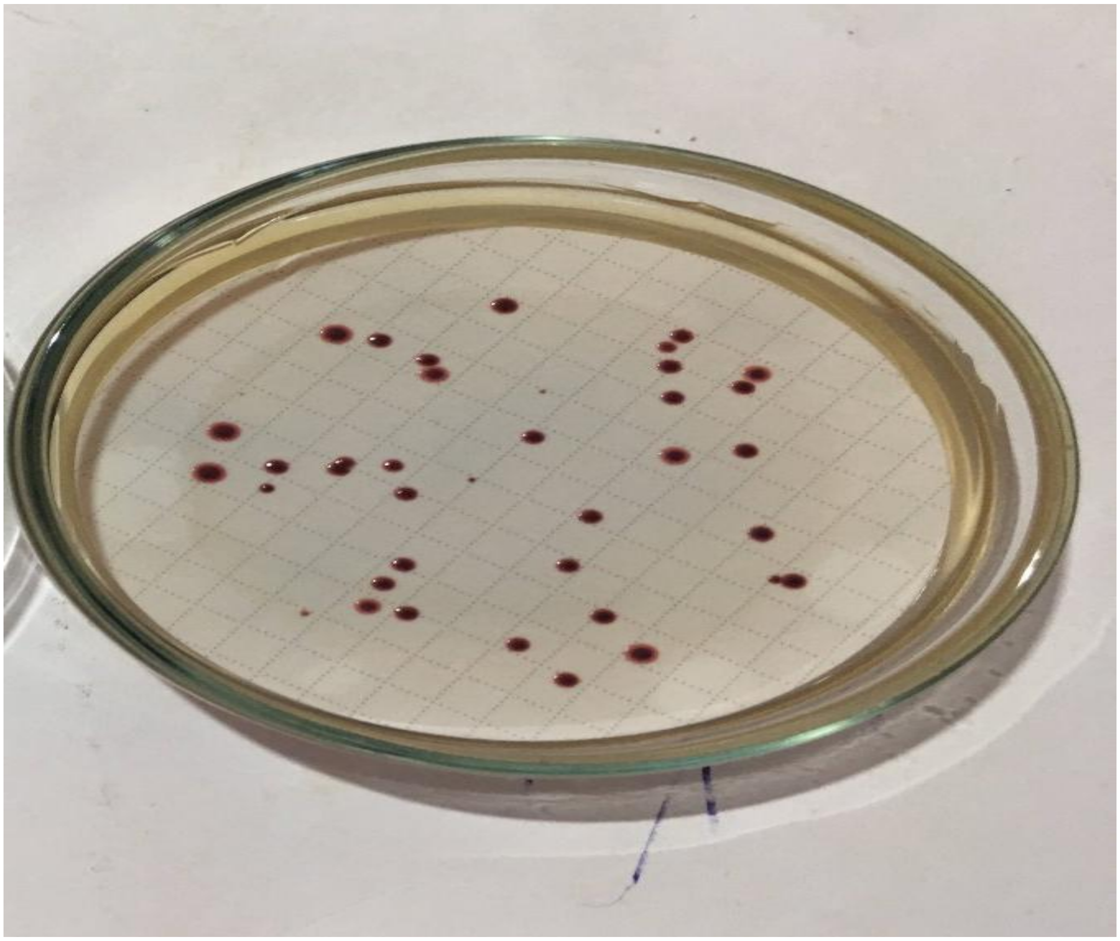
GEOGRAPHIC COORDINATES DATA

SITE ID	CORDINATES
Tua BH	N9° 21.684' W0° 47.691'
TPH BH	N9° 25.755' W0° 52.180'
Sognaayili BH	N9° 27.211' W0° 52.767'
Post Off. BH	N9° 24.418' W0° 50.408'
SSNIT area BH	N9° 24.418' W0° 50.408'
OLA area BH	N9° 24.076' W0° 49.976'
Target area BH	N9° 22.883' W0° 48.848'
Dabokpa area BH	N9° 23.289' W0° 48.993'
Stadium area BH	N9° 24.769' W0° 51.689'
1st November area BH	N9° 27.049' W0° 51' 57'
Choggu FS area BH	N9° 25.450' W0° 51.343'
Choggu CW HDW	N9° 25.487' W0° 51.365'
Womale HDW	N9°23.179' W0°46.505'
Dufaa HDW	N9° 20.984' W0° 45.011'
Bamvim HDW	N9° 21.710' W0° 50.266'
Junshegu HDW	N9° 21.284' W0° 50.950'
Kammonnaayili HDW	N9° 21.967' W0° 53.002'
Queen Elizabeth HDW	N9° 24.434' W0° 50.285'
Gbanyemini HDW	N9° 28.356' W0° 49.317'
Vittin top HDW	N9° 22.883' W0° 48.843'

Sources: Field data, 2021

APPENDIX TWO

PLATES SHOWING BACTERIA GROWTH



Bacteria culture plate