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DETERMINANTS OF HOUSEHOLDS' ACCESS TO IMPROVED WATER SOURCES, GEOSPATIAL MODELLING AND WATER QUALITY MONITORING IN TALENSI DISTRICT

BY

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DECLARATION

I hereby declare that this thesis is the result of research undertaken by Maame Serwa Opare-Boafo towards the award of Doctor of Philosophy in Public Health and that: to the best of my knowledge, it neither contains materials previously published by another person nor material which has been accepted for the award of degree in any university, except where due acknowledgement has been made in the text and the reference section. This thesis write-up was done under the joint supervision of Prof. Mawuli Dzodzomenyo, Prof. Jim Wright, Prof. Duah Dwumoh and Dr. Reginald Quansah.

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DEDICATION

I dedicate this work to God Almighty for His grace and protection through this academic journey.

To my late mother Rosemund Amponsah Djan, I say thank you very much.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

As: Arsenic

CCME: Canadian Council of Ministers of Environment

CFU: Colony-Forming Unit

EA: Enumeration Areas

EC: Electrical Conductivity

E. coli: Escherichia coli

ETM+: Enhanced Thematic Mapper Plus

F^-: Fluoride

FDG: Focus Group Discussion

GDHS: Ghana Demographic and Health Survey

GIS: Geographic Information System

GSS: Ghana Statistical Service

Hg: Mercury

HPC: Heterotrophic Plate Count

IARC: International Agency for Research on Cancer

IDW: Inverse Distance Weighting

IPCS: International Programme on Chemical Safety

JMP: Joint Monitoring Programme

KII: Key Informant Interview

LULC: Land Use/Land Cover

MICS: Multi Indicator Cluster Survey

NASA: National Aeronautics and Space Administration

NO^-: Nitrate

OLI: Operational Land Imager

OPD: Outpatient Department

pH: Potential of Hydrogen

Pb: Lead

QMRA: Quantitative Microbial Risk Assessment

TDS: Total Dissolved Solids

UNICEF: United Nations International Children’s Emergency Fund

USEPA: United States Environmental Protection Agency

USGS: United States Geological Survey

WHO: World Health Organization

WQI: Water Quality Index

WGS: World Geodetic System

WRC: Water Resources Commission

ABSTRACT

The study assessed factors that influence households' access to improved water sources in both rainy and dry seasons, likewise the impacts of land use and land cover on water quality. Water quality at intake and point of consumption was also determined as well as seasonal variation. The quality of water was evaluated by applying Canadian Council of Ministers of the Environment Water Quality Index model (CCME WQI). Non-carcinogenic risk associated with chemical exposure was achieved based on the estimation of hazard quotient and hazard index and quantitative microbial risk assessment (QMRA), which was used to estimate the disease burden and risk of infection due to microbial contamination of water. Geospatial analysis and techniques enable us to measure and estimate water quality, and the population at risk and visualize it over a space using Geographic Information System.

The study found that households' access to improved water sources significantly improved from 81.67% in the dry season to 90.83% in the rainy season ($p<0.0012$). In both survey seasons, compared to residents in non-mining communities, residents in mining communities were less likely to have access to improved water sources. At higher temperatures 27.79-27.98, households had lower odds of having access to improved water sources in the dry season. According to the Land use/Land cover map, there was a significant decrease in water levels during the dry season.

The analysis conducted on the median difference in water quality parameters among water sources and households revealed significant deterioration in some water quality parameters in households. Total Coliform was higher in the households compared to the main sources ($z = -2.337$, $p = 0.0195$), Faecal Enterococci ($z = -2.100$, $p = 0.0357$), and E. coli ($z = -2.907$, $p = 0.0037$) were also higher in the households compared to the main source.

Seasonal variation of water pollutants revealed a strong negative impact of rains on microbiological contaminants. Total coliform decreased in the dry season ($Z=3.379$, $p=0.0007$), Faecal Enterococci deteriorated during the rainy season ($Z = 4.270$, $p = 0.0000$), There was higher in E. coli, Salmonella and Shigella during the rainy season respectively (Z= 5.410, p = 0.0000, Z= 3.602. P= 0.0003 and Z= 3.726, p= 0.0002).

The study revealed some physico-chemical and metals having lower concentrations during the rainy season than the dry season. pH levels tend to be higher in the dry season compared to the rainy season (Z = -2.220, p = 0.0264). Temperature was also higher during the dry season than the rainy season (Z= -9.223, P= 0.0000). TDS of the water was significantly lower in the rainy season (Z = -2.133, p = 0.0329).

Sanitary inspection conducted at the main source and household showed that most boreholes and other water sources were installed near source of pollution with the majority of the pumps damaged at the point of attachment. Most of the households' sanitary practices were not in accordance with UNICEF and WHO guidelines. The risk priority matrix showed that in the rainy season, 64% of the water points analyzed had a very high risk of Total Coliform contamination based on the established threshold by WHO. For the dry season, bacteriological testing revealed that 34% of the sites had counts greater than 100 CFU/10mL, 42% had Total Coliform counts between 11 and 100 CFU/100mL and 12% had low risk.

The study found that arsenic levels in water samples pose a significant carcinogenic risk to residents, with 16% below detection limits, 14% within optimal range, 70% above thresholds during the rainy season, and 60% below detection limits, with 8% within the optimum range and 32% above the threshold during the dry season. The hazard index (HI) for As, Hg, and F- varied during the rainy and dry seasons. The target organ for these ions is the kidney, with 16% of sample points exceeding the safe limit. For Arsenic and Nitrate, targeting the liver, 10% of points were above the safe limit, while 2% were recorded in the rainy season. QMRA on the other hand indicated significant differences in the diseases burden arising from the various sources of water. A major part of the annual risk of infection originated from Shigella (9.89×10^{-1}) was from the

household and the least important contributor was E. coli at the main source. The majority of the water points had disease burden higher than the reference standard set by WHO of (10^{-6}).

The water quality map showed areas with good to excellent water quality for human consumption. During the rainy season, western parts like Balungu and Shia have marginal water quality, while eastern parts like Gbane Kejetia and Gbane Obuasi have marginal water quality. In the dry season, most eastern water points improve, while western Balungu has marginal water quality. The study identified areas with groundwater fluoride levels exceeding 1.5 mg/L, affecting the population relying on groundwater for daily needs. The north-western (Shia) part of the district was at high risk, with fluoride levels above WHO reference standards during both survey seasons. A total of 438 children between the ages of 0-15 years were at risk as a results of Fluoride exposure during the dry season while 516 children were at risk during the rainy season. An estimated of 1950 people were potentially exposed during the dry season and 2012 during the rainy season.

CHAPTER 1

INTRODUCTION

1.1 Background

Access to improved water sources has significantly increased on a global scale. However improved water coverage in countries in Sub-Saharan Africa still have considerably lower than in other countries (Eberhard, 2019). Despite the overall increase in global access, the World Health Organization (WHO) estimated that 144 million people drink untreated surface water and 58% of these people live in sub-Saharan Africa (Jepson et al., 2017). It was declared by the General Assembly of UN that everyone has the right to access improved water, but there are still inequalities with respect to global access because 2.2 billion people lack safely managed drinking water (Neto & Camkin, 2020). Projections showed that more than half of the world's population will experience mild water stress by 2050, with 80% disproportionally falling on developing regions. Recent reports from UNICEF/WHO denote dramatic acceleration to achieve SDG 6 in Africa. The special reports revealed that approximately 500 million more individuals had access to clean drinking water between 2000 and 2020. However, 418 million people still lack access to even the most basic supplies of drinking water. (UNICEF/WHO, 2021).

According to 2019 definitions by WHO/UNICEF Joint Monitoring Programme (JMP) improved water source are the type that, by virtue of their structure and design, can protect the source from outside contamination in particular from feacal matter. Residents need to use an improved source that is readily available on the property and accessible when needed, to meet the requirements for properly managed drinking water services and free from contamination. The improved source is categorized as a basic drinking water service if it satisfies none of these requirements but requires less than 30 minutes to collect water round trip. (WHO & UNICEF, 2019).

Despite global progress, discrepancies between urban and rural area access to improved water sources still exist (GDHS, 2014; MICS, 2017; UNICEF, 2016). In Ghana, people in rural communities (76%) are less likely to have access to improved water sources compared to people in urban communities (88%) (MICS, 2017). Current reports from the United Nations state that 3 million people in the country used surface water (Angela, 2021). The majority of water-borne illnesses and fatalities are caused by surface water sources because humans are exposed to microorganisms, chemical pollutants, and radioactive risks in the water (WHO, 2019). The impact on the mortality rate is devastating with more than 700 children under five dying every day from diarrhoea diseases as a result of ingestion of water polluted with faecal matter, as well as poor sanitation and poor hygiene (Charles & Greggio, 2021). It is estimated that 80% of all illnesses and diseases worldwide are thought to be caused by drinking contaminated or hazardous water (Shaffer *et al.,* 2019). Diarrhoeal illnesses worsen malnourishment and continue to be a major cause of death for children worldwide. (Cissé, 2019; Vunian et al., 2019). Individuals with weakened immune systems, such as those with HIV and AIDS, are less able to fend off or recover from infections contracted through water. (UNICEF, 2008). Despite the fact that groundwater has far superior microbiological quality than surface water, an increasing number of water sources that people use for cooking and drinking are not sufficiently protected against faeces. (Parker, 2000; Dzodzomenyo et al., 2022). Contamination of water has led to the establishment of drinking-water quality standards that public water sources must meet or exceed. The World Health Organization, The International Atomic Energy Agency, and the Food and Agricultural Organization of the United Nations have established international standards in relation to chemical, biological and physical (radiological) parameters for safe human consumption (WHO, 2019).

The quality of groundwater and surface water resources in Ghana keeps worsening mainly due to land use such as illegal mining and farming. These activities release high levels of contaminants from waste, leachate from chemical fertilizers and pesticides, and chemicals from mining, into water sources. (Yeleliere *et al.,* 2018). The MICS survey conducted in 2017/2018 stated that close to 8 in every 10 household's drinking water was contaminated with *E-coli*. However, contamination of *E-coli* was higher in their drinking water than at the source where the water was collected.

1.2 Problem Statement

Access to improved water is necessary for the survival of human life. Even though there are international agreements to attain the Sustainable Development Goals (SDG) targets 6.1 and 6.3, there are still inequalities with access to improved water in Ghana. In Ghana, significant progress has been made towards improved water access, however there are regional disparities. Regions that are hydrologically challenged like the northern part of Ghana still have lower than the countries average access to basic drinking water (MICS, 2018). Aside from their low average access, the region is known to be the driest part of the country due to its geographical location and it is characterized by low annual rainfall and long dry seasons (Abdul-Rahaman & Owusu-Sekyere, 2017). The 2017/2018 MICS survey conducted in Ghana reported that eight in every ten households use basic drinking water services but regions in the Northern part of Ghana, still depend on surface water to supply their fundamental needs for water (Araya et al., 20222). Due to the low variable and unpredictable rainfall pattern, extreme climates destroy most of their sources of water. Torrential rainfall causes flooding which ends up submerging and polluting some water sources with debris and fecal matter (Mensah & Ahadzie, 2020; Dzodzomenyo et al., 2022). The MICS report also indicated that 87.7% of households in the Upper East do not have drinking water on their premises and thus about 70.8% spend a collective time of 30 minutes walking for improved water source. Distance travelled to transport water from the main source to the house can compromise the quality of water (UNICEF, 2008; Wright et al., 2004).

Despite the increase in improved water access in the Upper East region, not all these sources provide safe water. Water from majority of improved sources is of poor quality. The widespread of natural fluoride contamination of boreholes in Bongo, Northern Ghana is a typical case (Affam et al., 2012; Craig et al., 2018; Zango et al., 2021; Araya et al., 2022).

About 64% of the people living in Talensi district use improved water sources ranging from small town water system, boreholes and dams (Chahu et al., 2025). Generally, the quality of ground water in these communities deteriorates moving towards the northern of part of the district whereas waters in the east and west present the best. The chemical quality of groundwater is influenced by the weathering of the rocks in the district (Yidana et al., 2012; Tay, 2017).

Silicate and carbonate mineral weathering was identified as the main controls on groundwater chemistry in the district, with reverse ion exchange also playing a role. High nitrate and lead levels observed have been associated with agrochemicals and wastewater from farms and homes (Chegbeleh et al., 2019).

Illegal mining (galamsey), pesticides and fertilizer run off from Agriculture sites contaminate ground water and surface water.

Efforts have been made by non-governmental organisations, multilateral organizations and government to provide safe drinking water in the Talensi district through various measures, such as constructing small town water systems and drilling boreholes in the rural areas (United Nations, 2021). However, these interventions are hindered by poverty prevalence in these areas. The local populaces are not able to afford the maintenance of water facilities therefore increasing the problem of unsafe water consumption in Talensi. Also, climate change events such as flooding, torrential rain and drought further increase the current problem of low access to improved water. Water security is highly susceptible to climate change and variability (Kotir, 2011). The problem of illegal mining in the district also exacerbates poor access to safe water.

Some studies have been conducted on household access to improved water sources using secondary data but none of those studies looked at the seasonal impact and environmental variables on improved water access by households. Likewise, water quality has been widely reported in the country, but the information on the spatial distribution of water quality and water pollutants and the estimated number of people exposed to these pollutants is limited. The rationale for developing a fluoride hazard map for the Talensi district stems from the presence of several communities in the area with fluoride concentrations in drinking water that exceed the World Health

Organization's (WHO) recommended limits. Despite this public health concern, there is currently a lack of detailed, spatially explicit data on fluoride distribution within the district. This gap is significant because without localized hazard mapping, it is difficult for policymakers, health officials, and communities to identify high risk areas and implement targeted interventions.

In addition, data on sanitary risk assessment of water sources and microbial risk assessment are scanty; therefore, it is important to analyse the factors that influence households' improved water access, the effects of changing land cover and use on the amount of water available, and the health risks to humans posed by exposure to water contaminants, as well as their spatial distribution and the population at risk.

1.4 Justification

Despite the significant progress with regard to access to improved water, two billion people, or 26 percent of global population, still do not have access to properly managed drinking water and inequalities persist not only within Sub-Saharan Africa but also throughout many of its nations' urban and rural environments. (Dos Santos, 2017). Nearly 80% of household members in Ghana have access to improved water sources but not all these sources are necessarily safe for consumption (MICS, 2017). Estimates indicate that 66% of households in the country drink water contaminated with fecal matter (Bain et al., 2020). Water extracted from protected source or improved sources might be polluted at the point of consumption due to unsafe handling, time spent, distance travelled to collect, and storage of water (Wright et al., 2004). Deteriorating water quality also threatens the SDG6 "ensure availability and sustainable management of water and sanitation" and 3, "ensure healthy lives and promotion of well-being for all at all ages".

This study also looks at the impacts of seasonality on households' access to improved water sources. It also assesses the effect of changing land cover and use on the impact on the amount and quality of water. It also seeks to ascertain how water pollutants are distributed in the study area with the population at risk as well as areas with good and poor water quality. Based on the resident's access to improved water sources and other secondary data analyses, a map will be generated to identify the spatial distribution of water quality and water pollutants in the district. Changes in land cover and use map will also be generated for the survey season. The study will result in policy recommendations for the Ministry of Sanitation and Water Resources, Environmental Protection Agency and Local Government and Talensi District Office. Moreso, the study will contribute to existing districts' literature on water security in districts towards the achievement of the District League Table which feeds into the country's SDGs (Targets 6, 6.1).

1.5 Conceptual Framework

The material gleaned for the conceptual framework was attained from literature. The availability of improved water sources is influenced by certain socioeconomic parameters, which has an impact on household living standards. Economic characteristics, family heads' educational attainment, and location of residence and distance to water sources, influence households' improved water access. Also, environmental factors like rainfall, temperatures, and land use and land cover influence households' access to improved water.

The study also focused on some water quality parameters such as chemical (Nitrate, Fluoride, Arsenic, Lead and Mercury). The intake of these contaminants leads to health outcomes mainly through continuous contact except for nitrate, which is an objection, as interim exposure can cause methemoglobinemia. Microbiological contaminants such as *E. coli, Shigella, Salmonella, Total coliform, and Faecal enterococci* can be detrimental to exposed population. Also, some physco-chemical analytes like pH, EC, TDS and temperature determines if water is good water for consumption. The computation of all these water quality parameters determines the overall water quality index which will establish if water is of good quality or poor quality. Human exposure to these water pollutants through ingestion of water will adversely affect their health. Access to improved water leads to improved health, or it reduces the incidence of waterborne diseases which improves living standards through reduction in disease burden. Finally Spatial modelling of water quality and water pollutants with the estimated population exposed may help determine households' exposure to water pollutants. Below is a conceptual framework that illustrate the household access to improved water sources, human health risk assessment geospatial modelling of water pollutants and population at risk in Talensi district.

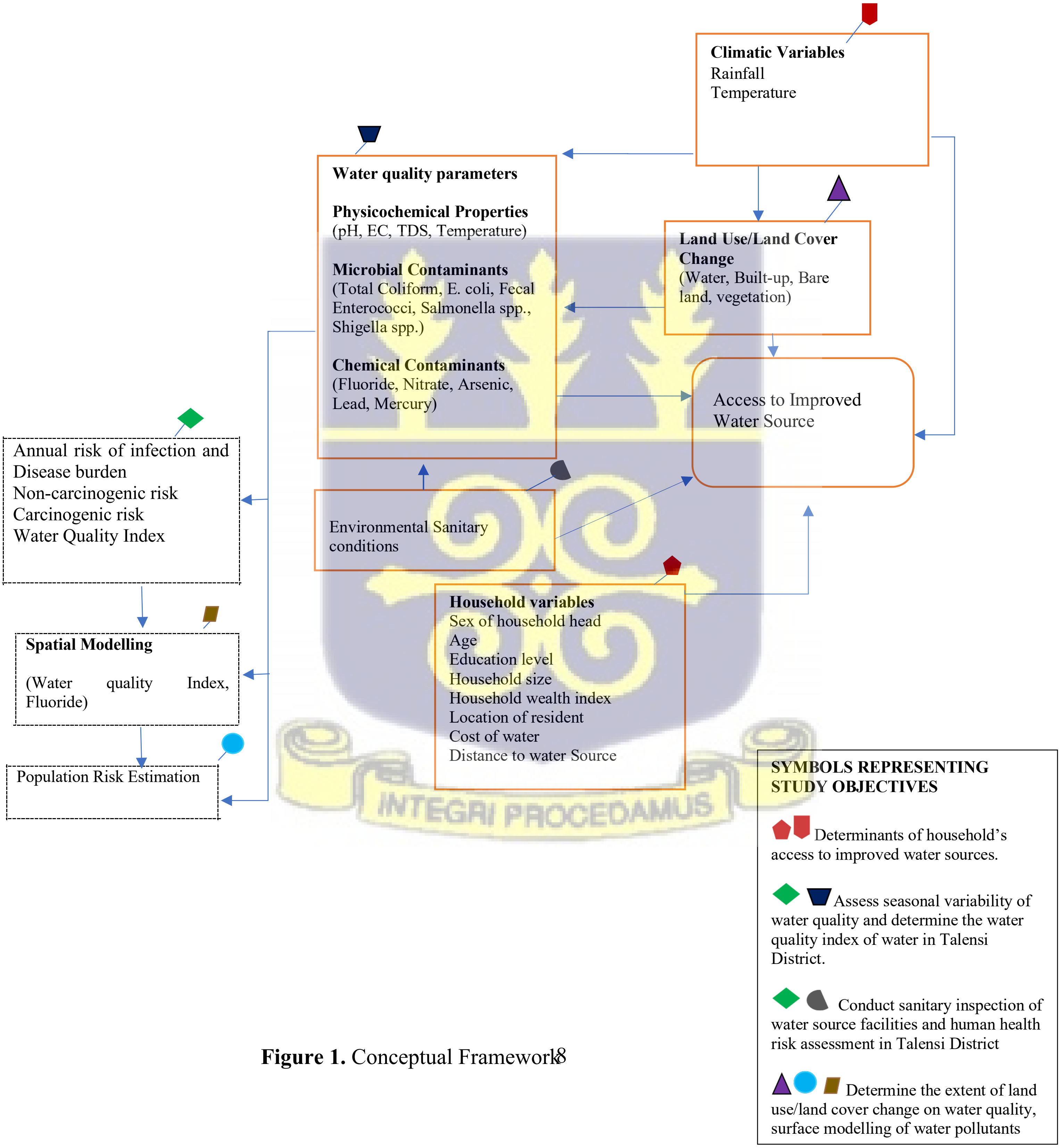


Figure 1. Conceptual Framework

1.6 Research Questions

The purpose of this study was to respond to the following questions:

1. What are the factors associated with households' access to improved water sources in Talensi District during rainy and dry season?
2. What are the levels of water pollutants in water from the Talensi District
3. What is the human health risk associated with water utilized by households in the Talensi District?
4. What is the extent of land use change on water quantity and quality, and surface interpolation of water pollutants in Talensi District and the estimated population at risk?

1.6 Aim/General Objective:

- To determine geospatial distribution, water quality and factors associated with households' access to improved water in the Talensi District.

1.7 Specific objectives:

- To examine factors that influence households' access to improved water sources in the Talensi District during rainy and dry season.
- To assess a seasonal variability of water quality and to determine the water quality index of water in Talensi District.
- To conduct sanitary inspection of water sources fand human health risk assessment among residents in Talensi District.
- To determine the extent of land use/land cover change on water quality, surface modelling of water pollutants and estimated population at risk.

1.8 Hypothesis

The study hypothesized the following:

- Null hypothesis (Ho): None of the predictor variables have a statistically significant relationship with access to improved water sources.
- Alternative hypothesis (Ha): The predictor variables (household size, socioeconomic status, education level, temperature, and rainfall) have a statistically significant relationship with access to improved water sources.
- Alternative hypothesis (Ho): There is no significant impact of land use /land cover change on water quality.
- Alternative Hypothesis (Ha): There is significant impact of land use /land cover (mining, farming, settlement and vegetation) change on water quality.
- Null hypothesis (Ho): There is no significant difference in households' access to improved water source in both survey seasons.
- Alternative hypothesis (Ha): There is a significant difference in the households' access to improved water source during the rainy season than in fry season.
- Null hypothesis (Ho): There is no significant difference in the concentration of water pollutants in both survey season.
- Alternative Hypothesis (Ha): There is a significant difference in the concentration of water pollutants (microbial contaminants) in the rainy season compared to the dry season.

1.9 Organization of the Study

There are six chapters in this thesis. An overview of the information on the availability of improved water, contributing factors and current gaps is provided in chapter one. In addition, the chapter covers the conceptual framework and its description, research question and study objectives. The literature review on households' access to improved sources, the significance of water pollutants, and Geographic Information Systems, land use and land cover are covered in chapter two. The study area/setting, eligible population, study design, sampling strategy and population allocation, data processing and statistical analysis, and ethical considerations are all covered in detail in Chapter three. Chapter Four presents the results section of the thesis including a summary of main findings, The discussion sections, findings' generalizability and transferability, strengths and limitations, and the study's addition to the literature are all covered in Chapter Five. The study’s conclusion and recommendations are provided in Chapter Six.

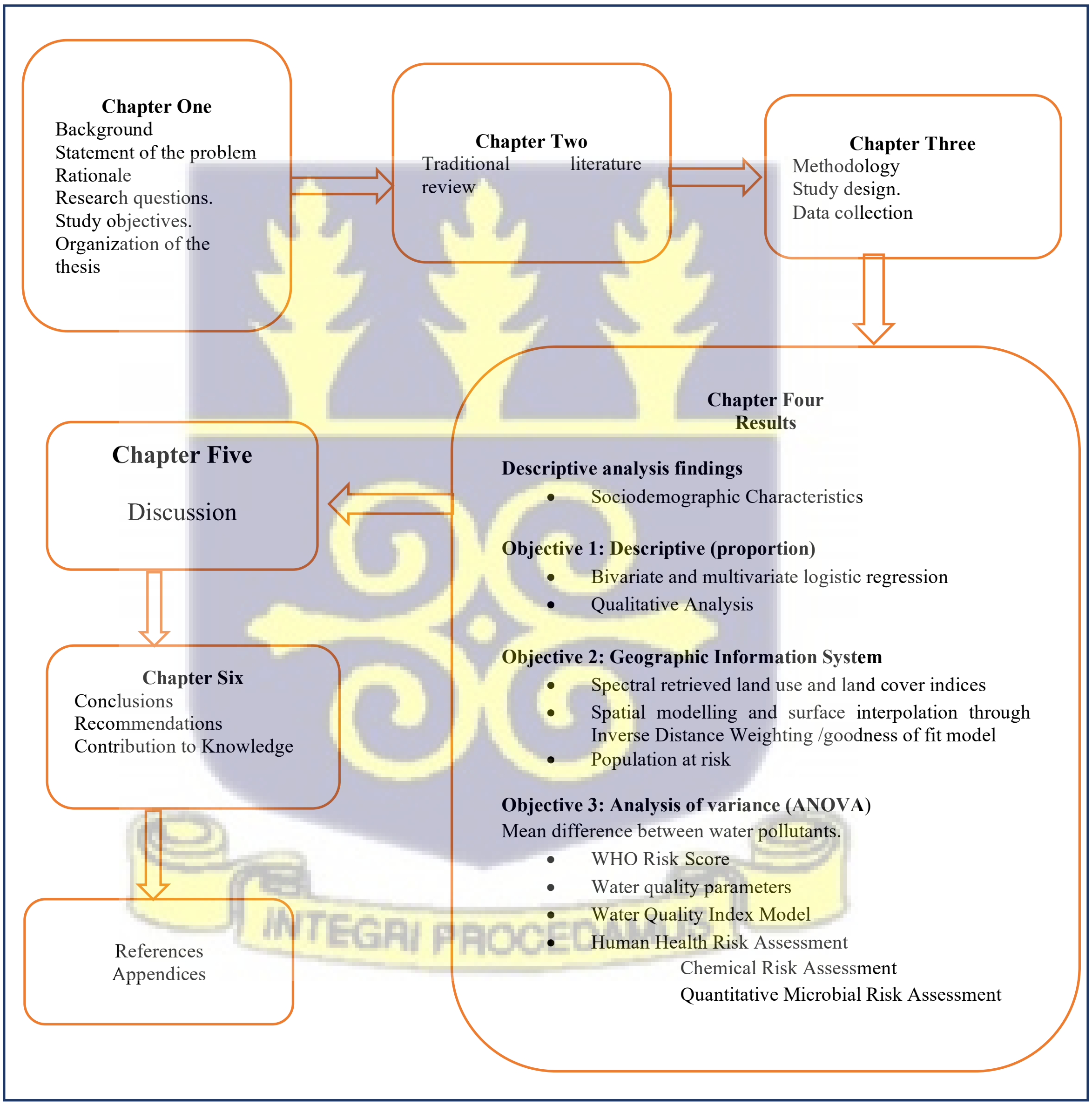


Figure 2: Schematic presentation of the thesis

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter aims to determine the current state of knowledge on access to improved water source and water pollution by discussing relevant water quality parameters and their significance in relation to water pollution assessment. It also reviews available policy instruments for water pollution management to better understand their implications. It covers among others access to improved water and sources of water in Ghana. It also highlights the significance of water parameters, land use and land cover, spatial interpolation, and groundwater flow modelling.

2.1 Sources of water in Ghana

Ghana is well endowed with abundant water resources and has three main river systems namely the Volta River System Basin, covering about 70% of the entire country, the Southwestern River System covering 22%, and the remaining 8% comprise of the Coastal River System (WRC, 2015). The Volta River System is the largest and most important river system in Ghana, with its main source in Burkina Faso. The system provides the country with a significant amount of hydroelectric power, as well as water for irrigation, fishing, and transportation (WRC, 2015). The Southwestern River System, which includes the Ankobra, Tano and Bia rivers, provides water for irrigation and fishing, while the Coastal River System, which includes the Pra, Densu and Ayensu rivers, is used for drinking water supply and irrigation. The Densu basin in the coastal river is of key importance to water supply in the capital city of Ghana, Accra. The estimated annual runoff from the 3 river systems in Ghana is 40 billion m^3 out of the 53 billion renewable freshwater (Obuobie & Barry, 2010). The Volta River System consists of the Black, White and Main/Lower Volta, Oti and Daka Rivers. It has a surface area of about 8,500Km^2, an average depth of about 18.8m and a shoreline of about 5,500 Km (Barry et al., 2005). The deepest portions of the lake are about 90m. The total volume of water in the reservoir at full supply level is about 84.73m, approximately 150 billion m^3 (Barry et al., 2005). The rainfall pattern in the country is bimodal in the south and mono-modal in the northern part. The Northern part has insufficient water because evapotranspiration exceeds the rainfall (Bessah et al., 2021a).

2.2 Access to Improved Water

Improved water source is defined by the WHO/UNICEF Joint Monitoring Programme (JMP) 2017 as those that have the potential to deliver safe water by nature of their design and construction. Based on the quality of service, they further divided the population using improved sources into three groups. To meet the criteria for safely managed drinking water services, households are required to use an improved source that is free from contamination, accessible on-site, and available when needed. If the improved source does not meet any of these requirements but requires less than 30 minutes to collect water, it is considered basic drinking water (WHO & UNICEF, 2017). Access to improved water sources is well documented. A survey conducted in selected low-income urban areas in Accra revealed that only 4.4% of respondents had access to improved drinking water, while the WHO definition puts that number closer to 40.7 Nonetheless, according to Matuamo Mahama et al. (2014), 88.7% of the respondents had access to improved water for home usage, compared to 93.3% when applying the WHO definition. Further analysis in the same study based on logistic regression showed that income was the significant determinant of households' access to improved drinking water while access to improved drinking water for other domestic uses had significant factors like education, income, and location of household. These results are inconsistent with evidence in literature. Using the Ghana DHS dataset, Agbada et al., (2019) concluded that female headed households, education, urban households, and income, have significant association with household access to improved water sources.

2.3 Access to Improved Water in Ghana Past and Present

Despite the significant progress with improved water access in Ghana, one person out of every ten must spend more than 30 minutes to access an improved source of water. Also, 11% of the population still drink from surface and other unsafe water sources (MICS, 2018). Ghana was able to achieve the Millennium Development Goal 7 by halving the population without access to improved water sources (GDHS, 2014). Reports from the Ghana Demographic and Health Survey indicated that in 2008, 77 percent of households obtained drinking water from an improved source. Fourteen percent of households had access to piped water in their dwelling, yard, or plot, while 29 percent accessed drinking water from a public tap. Thirty-three percent of households got their drinking water from a tube well or borehole, or a protected dug well. Thirteen percent of households use unimproved sources of drinking water and about 9 percent use either bottled or sachet water. Surprisingly, there is little difference between urban and rural households in access to improved sources of drinking water. In 2008, there was 23% decline in households having water on their premises (DHS, 2008). This decline could be attributed to the decline in the percentage of households in urban areas with water on their premises, from 42 percent in 2008 to 22 percent in 2014. However, there was a substantial increase in the proportion of urban households that spend less than 30 minutes to obtain water, from 51 percent in 2008 to 71% in 2014.

In 2014, 70% of households spent less than 30 minutes to obtain their drinking water, with no major differences between urban and rural households. Fifteen percent of households spend 30 minutes or longer to obtain their drinking water, in rural areas compared with only 7 percent in urban areas. In 2017, 86% of households used improved water sources whiles 79% used basic, 40% used improved sources that is available on the premises, 89% used improved sources available when needed, 59% used improved water free from contamination and 19% used safely manged drinking water (MICS, 2018). Reports from the 2021 Population and Housing Census indicated that 87.7% of the populace have access to basic water supply services. Yet, there are urban and rural disparities. About 96.4% of the urban populace have access to basic water supply services while 74.4% of the rural populace have access to basic water supply services. About 8% of Ghanaian households continue to rely on unsafe water sources (PHC, 2021).

2.4 Water Quality

Water quality is a growing concern throughout the developing world. Drinking water sources are decreasing in quality and quantity. Deteriorating water quality threatens global progress made in improving access to drinking water (Van Vliet et al., 2021). Surface water and groundwater quality has long been deteriorating due to both natural and human-related activities. Natural factors that influence water quality are hydrological, atmospheric, climatic, topographical, and lithological factors (Magesh et al., 2013; Uddinet al., 2018). Mining, livestock farming, production, and disposal of waste (industrial, municipal, and agricultural), and increased sediment run-off or soil erosion due to land-use change are some of the anthropogenic activities that affects water quality (Lobato et al., 2015).

Chemical contamination of water supplies occurs both naturally and from man-made pollution, which is a very serious problem. Arsenic and fluoride alone threaten hundreds of millions of people (WHO, 2011). Water contamination by microbial agents is a major contributor to diarrheal diseases which kill millions of children every year (WHO, 2011). Serval water quality studies have been carried out in most parts of the world. Previous DHS and MICS studies conducted in the country did not include water quality tests but in recent years it has been included. Mawuli et al., (2022) reported on the increasing levels of thermotolerant coliforms and E. coli during the flood season in Northern Ghana. Yet a study conducted by Chegbeleh et al., (2020) in the Talensi District in Northern Ghana suggested that groundwater from the unconfined aquifers of the district was of excellent quality for irrigation purposes. Also, Ebenezer et al., (2021) concluded that consuming water from Bolgatanga in Northern Ghana was likely to pose negative health effect on children and adults.

2.5 Water Quality Parameters

The safety of water depends on its quality, which is determined by the presence of contaminants. Generally, the quality of water is evaluated by a range of parameters which is described by chemical, physical and biological characteristics. (Meybeck and Helmer 1992).

Regulatory agencies like the World Health Organisation, the Environmental Protection Agency (EPA) in the United States and similar organizations in other countries have established drinking-water quality standards for various parameters such as microorganisms, disinfectants, disinfection by products, inorganic chemicals, organic chemicals, and radionuclides (WHO, 2019). These standards ensure that water from public sources is safe to drink and meets certain health-based criteria. Public water systems are required to regularly test their water and report any violations of these standards. This study considered some physical, chemical, and biological water quality parameters, which include temperature, pH, total dissolved solids (TDS), electrical conductivity (EC), nitrate (NO_3^-), fluoride (F^-), Total Coliform, E. coli, Fecal Enterococci, Salmonella spp., Shigella spp., Arsenic (As), Lead (Pb), and Mercury (Hg). Most studies conducted in the country either look at microbial parameters alone or chemical parameters.

2.6 Significance of Selected Water Quality Parameters

2.6.1 Temperature

Temperature can lead to increased levels of dissolved oxygen consumption, decreased water pH, and changes in the solubility and precipitation of minerals (Chapman et al., 2018). Temperature also affects the biological activity in water, especially in aquatic habitats. As water temperature changes, it can influence the metabolic rates of aquatic organisms, such as fish, invertebrates, and algae, potentially altering their growth, reproduction, and survival (Metcalf and Eddy 1991). Temperature can also influence the dissolved oxygen levels, nutrient status, and microbial activity of water systems (Bhateria & Jain, 2016). Water with high temperatures, particularly groundwater, can dissolve more minerals from surrounding rock resulting in high levels of electrical conductivity. Warm water holds less dissolved oxygen than cool water (Chapman and Kimstach 1992). On the contrary, high-water temperatures may lead to the problem of unwanted growth of water plants and wastewater fungus (Metcalf and Eddy 1991). Geographical position, seasonality, diurnal period, circulation of air, quantity of cloud cover, depth of water and its flow rate are some of the factors that influence water temperature (Davy et al., 2017). If water temperature rises above 16°C, it causes micro fungi to grow inside the internal plumbing system or mold taste (Hageskal, 2006). The temperature of water can affect chemical treatment and the delivery of portable water (Porcelli & Judd, 2010). Usually, chemical reaction decreases with decreasing temperature (Clarke and West 2018).

2.6.2 pH

The pH of water is a measure of the acid-base equilibrium and, in most natural waters, it is controlled by the carbon dioxide-bicarbonate-carbonate equilibrium system (WHO 2011). The pH scale ranges from 0 to 14, which is from very acidic to very alkaline while 7 indicates neutral condition (Yang et al., 2019).

As carbon dioxide concentration increases, pH decreases. pH can be affected by temperature (Pearson and Palmer, 2000). A rise in water temperature to 25°C can cause a decrease in pH to 0.45. The pH of most drinking-water lies within the range 6.5–8.5 (WHO, 2011; Iticescu and Maurariu, 2012). Natural waters can have lower pH, because of acid rain or high pH in limestone areas (Wei, et al., 2019). pH is an important parameter in determining the quality of water for human use and consumption. A low pH can indicate the presence of pollutants such as acid rain or industrial waste runoff (Kaushal et al., 2018). Additionally, a low pH can make water more corrosive, leading to damage to infrastructure such as pipes and pumps which tends to affect the taste and appearance of drinking water (WHO 2007). Therefore, monitoring and maintaining appropriate pH levels in water sources is crucial for ensuring the safety and quality of drinking water.

2.6.3 Total Dissolved Solids

Total Dissolved Solids are made up of inorganic salts as well as a small amount of organic matter. Inorganic salts mostly found in water include calcium, magnesium, potassium, and sodium which are all cations and anions like carbonates, nitrates, bicarbonates, chlorides and sulfates (WHO 1999). These minerals originate from different sources both natural and anthropogenic activities. Water that flows through a region where rocks have high salt content has high levels of dissolved solids (Selvakumar et al., 2017). Human activities such as wastewater discharge, agricultural and urban runoff and industrial wastewater can carry excess minerals into water sources (Owa, 2013). No recent data on health effects associated with the ingestion of TDS in drinking water appear to exist; however, it has only been reported in two limited investigations. Evidence of health effect associated with the ingestion of TDS in drinking water is not available (WHO, 2003).

The results of early epidemiological studies suggest that even low concentrations of TDS in drinking water may have beneficial effects (WHO, 2010). Certain components of TDS, such as chlorides, sulphates, magnesium, calcium, and carbonates, affect corrosion or encrustation in water-distribution systems (Nollet, 2000). High TDS levels (>500 mg/litre) result in excessive scaling in water pipes, water heaters, boilers, and household appliances such as kettles and steam irons. Such scaling can shorten the service life of these appliances (Nollet, 2000).

2.6.4 Electrical Conductivity

Electrical conductivity in water is a measure of salinity and the ability for water to pass an electrical current. These conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides, and carbonate compounds. It is expressed as micro siemens per centimeters (µS/cm) (Omer, 2019). The more ions (charged particles such as sodium, potassium, calcium, and magnesium) that are present in water, the better the water can conduct electricity. This is because the ions can carry the electrical charge through the water (USEPA, 2012). Conversely, pure water has an exceptionally low conductivity because it lacks ions to conduct electricity. Sea water, on the other hand, has a very high conductivity (SOEST, 2012). There is a positive correlation between water temperature and conductivity. The warmer the water, the higher the conductivity (Chapman et al., 2018). Conductivity is a water quality indicator. Changes in EC could be because of the direct discharge of pollutants entering water sources such as wastewater from sewage treatment plants, urban runoff and industrial plants (SWRCB, 2002). Basically, human disturbance tends to increase the level of dissolved solids entering waters which results in increased conductivity. Water bodies with elevated conductivity may have other impaired or altered indicators as well. Levels of EC in water can also be influenced by the composition of rocks of a watershed (USEPA, 2015).

2.6.5 Fluoride

Fluoride occurs naturally in the earth's crust as well as in water. When present in drinking water at optimum levels, it protects teeth from decay (Young, 1991). It makes the tooth enamel more resistant to acid erosion, helping to prevent cavities from forming. It is important to note that too much fluoride can be harmful to dental and overall health (Mullane, 2016). Ingesting elevated levels of fluoride can cause a condition called dental fluorosis, which can weaken and discolour tooth enamel (CDC, 2010). In extreme cases, excessive fluoride consumption can also lead to skeletal fluorosis, a debilitating bone disease (Kurland et al., 2007). In 1990, a study by the National Toxicology Programme, part of the National Institute of Environmental Health Sciences, revealed an increased number of osteosarcomas (bone tumors) in male rats given water containing high levels of fluoride for 2 years (Bucher., et al., 1991). In contrast, other studies in human and animal studies did not show any association between fluoridated water and cancer (National Research Council 1993; Kim et al., 2011). A report by the Public Health Service in 1991, found no evidence of the association between fluoride and cancer in humans. A current population-based study using cancer registry data found no evidence of an association between fluoride in drinking water and the risk of osteosarcoma or Ewing sarcoma (Blakey *et al.,* 2014; Archer *et al.,* 2016). Previous scientific literature produced conflicting results. However, based on the currently available evidence, most studies do not show a strong association between fluoridated water and increased cancer risk. Other evidence in literature has found a positive correlation between fluoride concentrations measured in maternal and umbilical cord blood plasma. This implies that the placenta allows passive diffusion of fluoride from mother to foetus (Gupta et al., 1993; Malhotra et al., 1993). The renal system, also known as the urinary system, is responsible for filtering and removing excess fluoride from the body hence, it is the organ that is exposed to high level of fluoride than the other organs (Whitford, 1996). This suggests that it might be at substantial risk to fluoride toxicity than other organs. Conversely there are only two published studies which suggest that the chronic ingestion of fluoride can have non- carcinogenic effects on the kidney, and both pertain to the incidence of kidney stones (Doull et al., 2006).

2.6.6 Nitrate

Nitrate is a naturally occurring ion in the environment and it is a byproduct of the oxidation of nitrogen (Environment Canada, 2003; IARC, 2010). The source of nitrate in water may include runoff or seepage from fertilized agricultural lands, municipal and industrial wastewater, refuse dumps, animal feedlots, septic tanks and private sewage disposal systems, urban drainage, and decaying plant debris (USEPA, 2006). Low levels of nitrates may occur naturally in water, especially groundwater, but sometimes higher levels can be detected in water because of anthropogenic activities (WHO, 2003). High levels of nitrate are potentially dangerous to infants (Zeman & Vlad, 2002). Additionally, prominent levels of nitrates can also lead to eutrophication in water bodies, which can cause harmful algal blooms and adversely affect aquatic ecosystems. WHO has adopted a drinking water standard of nitrate of 11 milligrams per liter (11mg/L) as nitrate (nitrogen) (WHO, 2011).

Elevated levels of nitrate in drinking water can pose health risks, especially for infants, pregnant women, and people with certain health conditions. Scientific studies published since the 1950s consistently show methaemoglobinaemia in infants as the endpoint of concern for nitrate exposure in humans (Shuval &Gruener, 2013). Methemoglobinemia is a condition where there is an abnormal amount of methaemoglobin in the blood, which results in reduced oxygen-carrying capacity of the red blood cells (Ash-Bernal et al., 2004). Infants are particularly vulnerable to nitrate exposure because their bodies are not yet fully developed to efficiently metabolize these compounds. Infants who drink formula made with water that has high nitrate levels are at a higher risk of developing methemoglobinemia. (Charmandari et al., 2001; Ward et al., 2005). Studies on health effect related to nitrogen exposure from drinking water have been reviewed by several authors and the International Agency for Research on Cancer (IARC). Findings from these studies concluded that ingestion of nitrate under conditions that result in endogenous nitrosation, is probably carcinogenic (Chambers et al., 2022). Also, the derived metabolites of the various nitrate and nitrite compound such as nitrous acid (HNO_2) are powerful nitrosating agents are known to drive the formation of NOC, which are suggested to be the causal agents in many of the nitrate-associated adverse health outcomes (d'Ischia, 2011).

2.6.7 Arsenic

The element arsenic is found naturally in the crust of the planet and is extensively dispersed throughout the ecosystem (Masuda, 2018). Many countries' groundwater naturally contains significant concentrations of arsenic (As), which is extremely poisonous in its inorganic form (Mandal & Suzuki, 2002). As is one of the ten chemicals that pose the greatest threat to public health, according to the World Health Organisation. According to the International Agency for Research on Cancer (IARC), drinking water containing arsenic is carcinogenic to people, and the agency has classified arsenic and its compounds as carcinogenic to humans (IARC, 2004). Acute effects of As exposure include vomiting, abdominal pain, and diarrhoea, which are followed by numbness and tingling of the extremities, muscle cramping, and, in extreme cases, death (Hughes et al., 2011). Long-term exposure to inorganic arsenic through drinking water can result in chronic arsenic poisoning. Human exposure to As can cause skin lesions and skin cancer as well as cancer of the bladder and lungs (Hong et al., 2014). Additionally, exposure in utero and early childhood exposure has been linked to negative impacts on cognitive development and increased deaths in young adults (Yoshi et al., 2004). Long-term ingestion of inorganic arsenic can also cause developmental effects, diabetes, pulmonary disease, and cardiovascular disease (WHO, 2011). Arsenic has been linked to adverse pregnancy outcomes and infant mortality, with impacts on child health *(*Quansah et al., 2015*)*, and exposure in utero and in early childhood is associated with increases in mortality in young adults due to multiple cancers, lung disease, heart attacks, and kidney failure (Farzan et al., 2013*)*. Numerous studies have demonstrated negative impacts of arsenic exposure on cognitive development, intelligence, and memory (Tolins & Landrigan 2014).

2.6.8 Mercury

According to Tchorunwou et al. (2012), mercury is a metallic element that exists naturally in the environment and has been widely disseminated by volcanic eruption. The amount of mercury used in industrial processes has also greatly raised environmental levels (Streets, et al., 2005). The condition in which mercury occurs determines how soluble it is in water. Mercury (II) chloride is easily soluble, whereas elemental mercury vapour is insoluble. According to Donatello et al. (2012), mercury sulphide has a very poor solubility and mercury (I) chloride is significantly less soluble. Both freshwater and saltwater undergo the crucial process of methylation, which is the oxidation of inorganic mercury (IPCS, 1989).

The body may absorb up to 15% of the mercury taken through water drinking. According to Park and Zheng (2012), the kidney is the primary organ targeted by inorganic mercury, and the element has an extended biological half-life. The kidney, liver, intestinal mucosa, sweat glands, salivary glands, and milk are among the organs that expel mercury salts; nevertheless, the excretion of mercury salts primarily occurs through the urine and faeces (Bradberry and Vale, 2014). Inorganic mercury compounds mostly cause harm to the kidney. Research conducted on male rats revealed that the kidney had a much higher absorption efficiency of mercury compared to the gastrointestinal system (Miura et al., 1981). Comparably, during a 26-week trial, mice administered varying dosages of mercury (II) chloride (0, 5, 10, 20, 40, or 80 mg/kg of body weight per day, indicated that most animals receiving the highest dose of 80 mg/kg of body weight per day died (NTP, 1993). A study by IPCS (2003) reported on the effects of mercury (II) salts on liver and adrenal because of oral exposure.

The two effects of mercury poisoning in humans are neurological and renal disturbances. Ingestion of 500 mg of mercury (II) chloride causes severe poisoning and sometimes death in humans (Bidstrup, 1964).

2.6.9 Lead

The most prevalent heavy element, lead, makes up 13 mg/kg of the crust of the planet. Typically, it is employed in the manufacturing of alloys, solder, and lead-acid batteries (WHO, 1989).

According to Cliff et al. (1996), the element contains multiple stable isotopes in nature. These include 208Pb, 206Pb, 207Pb, and 204Pb in order of abundance. Lead disintegrates in natural sources; therefore, it is rarely found in tap water. Instead, lead-containing plumbing parts, such as PVC pipes, are the source of lead in water (Schock, 1989). These lead compounds have a high potential to contaminate drinking water. Soft, acidic water is the most plumbosolvent, and the amount of lead dissolved from the plumbing system relies on a number of variables, including temperature, pH, softness, dissolved oxygen content, and standing time (Schock, 1990). There is no known safe amount of lead exposure, according to multiple lines of evidence from health scientists (Burns & Gerstenberger, 2014). Low-level lead exposure in children has been linked to neurological system damage, learning impairments, shorter stature, hearing loss, and decreased blood cell formation and function (Al Osman et al., 2019).

It is important to note that lead poisoning can have serious and long-lasting health consequences, especially in children who are more vulnerable to its effects. It is important to take steps to prevent exposure to lead, such as ensuring that water sources are free of lead and avoiding products that may contain lead. If someone suspects they or a loved one may have been exposed to lead, it is important to seek medical attention and get tested to determine the level of lead in the body (AAPC, 2005). A more recent review of lead in drinking water in rural areas of Ghana, Mali and Niger indicated that 9% of the drinking water samples had lead concentrations above WHO guideline value of 10 µg/L (Seltenrich et al., 2021). A recent study by Obiri-Yeboah on Bonsa river in Tarkwa Nsuaem a mining area revealed higher levels of lead than the permissible set by Ghana Environmental Protection Agency (Obiri-Yeboah et al., 2021).

2.6.10 E. coli, Fecal Enterococci, Total Coliform

Drinking water quality indicators, such as total coliform, faecal coliform, and E. coli, are used to monitor the safety of the water and notify authorities of any possible contamination (Standridge, 2008). The naturally occurring organisms known as total coliform bacteria are present in various environmental sources, such as soil and vegetation, and they usually pose little threat to humans. Nonetheless, the existence of these substances in potable water may suggest the possibility of external contamination (Ferguson et al., 2011). Heterotrophic Plate Count (HPC) data are helpful in evaluating the efficacy of treatment and distribution systems, and faecal enterococci are another indicator organism that is occasionally employed. Warm-blooded animals, including humans, only have faecal coliform bacteria in their intestines and faeces. Faecal coliform bacteria are a subgroup of total coliform bacteria. According to Niyoyitungiye & Ndayisenga (2020), their presence in drinking water suggests that there may be a source of faecal matter pollution. E. coli is a specific type of fecal coliform bacteria that is commonly associated with contamination from human or animal waste. Its presence in drinking water is a clear indication of potential fecal matter contamination and poses a serious health risk to consumers (Petersen, 2020). Globally, E. coli is the most widely used indicator for fecal contamination in drinking water supplies (Odonkor, 2013). Climatic conditions play an important role in the growth and proliferation of Microorganisms that exists in water bodies. An array of microbial communities plays a vital role in deteriorating water quality standards and it is totally responsible for making these water bodies unfit for human consumption. As per World Health Organization (WHO) standards, drinking water must not contain any total coliforms and thermo tolerant (fecal) coliforms.

Annually over 3 million people, mostly children die from water- related diseases. About 2 million of these deaths are the result of diarrhoeal diseases, which are caused by the ingestion of water contaminated by faecal matter, as well as by inadequate sanitation and hygiene (WHO, 2019).

A study conducted in Tano North Municipality revealed that most water sources analyzed were contaminated with bacterial pathogens surpassing WHO recommended standards thereby suggesting that residents living in the rural neighborhoods of the study area were exposed to heightened risks and susceptibility to waterborne diseases or health complications (Odonkor &

Mahami., 2020). A review of Ghana's water sources conducted by Yeleliere in 2018, outlined high contamination of the country's freshwater resources with E. coli. However, these contaminations were more prevalent in surface water than groundwater (Yeleliere., 2018). Other researchers have also studied the levels of E. coli in other parts of the country and detected high leave of E. coli in some of the water samples whiles other samples were free from this contaminates (Parker., 2011; Bekoe et al., 2021).

2.6.11 Shigella spp.

Gram-negative, nonsporulating, rod-shaped bacteria, Shigella spp. are members of the Enterobacteriaceae family (Bastos & Lourier 2011). There are four species in it. These are Shigella flexneri, S. dysenteriae, S. sonnei, and S. boydii. Based on variations in the O antigen and biochemical tests, they are further divided into different serotypes. Accordingly, there are 17 serotypes in Group A (S. dysenteriae), 14 subserotypes and classical serotypes in Group B (Shigella flexneri), one serotype in Group C (S. sonnei), and twenty serotypes in Group D (S. boydii) (Wei et al., 2003). Shigella is a group of bacteria that causes diarrhoea, fever, and stomach cramps. It is spread through contaminated food and water and can be particularly dangerous in areas with poor sanitation and hygiene practices. (Mahagamage et al., 2020). Contamination of water with Shigella spp., depends on the vulnerability of water sources to anthropological activities such as bathing, washing, and defecating (Mahagamage et al., 2016). Human exposure to this bacterium through ingestion of water can cause an infection called shigellosis or bacillary dysentery. Globally about 165 million cases of Shigella diseases are recorded, which lead to 1 million states of death, especially in the developing countries (Anderson et al., 2016).

2.6.12 Salmonella spp.

A family of facultative anaerobic gram-negative rod bacteria, Salmonella spp. can infect and cause illness in the digestive tracts of humans and warm-blooded animals. (Forshell, 2006). The main ways that humans get infected are through eating or drinking contaminated water. According to Rodriguez-Lazaro et al. (2012), these pathogens usually get into water sources by faecal contamination from sewage discharges, cattle, and wild animals. Typhoid fever/enteric fever, bacteraemia, septicaemia, and gastroenteritis can all be brought on by human exposure to these bacteria (Kariuki et al., 2015). Some people affected with Salmonella do not show any symptoms whereas most people develop diarrhoea fever and stomach (abdominal) cramps within 8 to 72 hours after exposure (WHO, 2018). With treatment, health people recover within a few days after exposure but in some cases, diarrhoea can cause severe dehydration. Reports from the Ghana Health Service has indicated that about 80% of all out-patient department (OPD) cases such as cholera, typhoid, and diarrhea are sanitation and water related (Andoh et al., 2017). Presence and persistence of *Salmonella* have been reported in surface waters such as rivers, lakes, and ponds in Ghana. Dekker et al., (2015) reported on Salmonella contamination of dug wells, with 99.2% of the samples tested contaminated with >100 CFU/100 mL Gram-negative rods. Earlier reports in the country have indicated the presence of *Salmonella* strains showing multi-resistance to antimicrobials routinely used as therapeutic agents (Mills-Robertson et al., 2003).

2.7 Water Quality Index

Water Quality Index model is a mathematical tool that is used for evaluating water quality. It is used to integrate the large and complex water quality data into a numerical score that best describes the overall water quality status (Ramesh et al., 2010).

Globally Water Quality Index (WQI) model has been applied to evaluate water quality of surface and groundwater based on local water quality criteria. Using ten water quality characteristics that were considered important in most waterbodies, Horton created the first WQI model in the 1960s (Horton, 1965). Later, Brown with support from the National Sanitation Foundation, developed a more rigorous version of Horton's WQI model, the NSF-WQI, for which a panel of 142 water quality experts informed the parameter selection and weighting (Abbasi & Abbasi 2012). To date, more than 35 WQI models have been introduced by various countries and/or agencies to evaluate surface water quality around the world (Kannel et al., 2007; Dadolahi-Sohrab et al., 2012; Ebenezer et al., 2020;)

The benefits of WQI have been well established; Darko et al., (2013) conducted a longitudinal study from 2005 to 2008 on the quality of surface water in the Southwestern and Coastal Rivers Systems of Ghana. This study looked at 10 water quality parameters namely Dissolved Oxygen, Biochemical Oxygen Demand Ammonium Nitrogen Faecal Coliform pH, Nitrate as Nitrogen Phosphate as Phosphorus Total Suspended Solids Conductivity and Temperature. Water samples were taken on bi-monthly intervals. The study revealed that the annual water quality decreased in the order: 2005>2007>2006>2008. According to the WQI classification of waters, most Ghanaian waters currently are practically in the Class II state or are of the fairly good water quality category (Darko et al., 2013). Potroase in the Densu Basin (on River Densu) recorded the highest water quality during the study period. Nsawam in the Densu Basin had the poorest water quality mainly due to pressure from human settlements and was consistently in the Class III state or the poor water quality category during the study period. Darko et al., (2013) concluded that the WQI was very useful for the classification of the waters monitored. Contrary to the quality of water in Ghana based on the Water Quality Index Model, Kaswanto et al., (2012) studied 8 water parameters; DO, COD, BOD, nitrite, nitrate, ammonia, and phosphate in four locations in Indonesia. Results from the study indicated that all the water samples were situated in good and medium level. The study's findings showed that all the water samples fell between good and medium levels. He concluded that WQI is an effective tool for evaluating water quality in rural areas. He said that non-scientific members of the public and decision-makers could easily understand the results thanks to the technology.

Also, fifteen water quality parameters (pH, EC, TDS, Ca, Mg, hardness, alkalinity, HCO3, Cl, Na, K, NO3, SO4, As, and Fe) were examined in another study carried out in Pakistan; however, only nine parameters were included in the WQI calculation because their given weights could be found in the literature. Most of the water from the two cities was found to be in bad condition by the research. 38 of the 53 filtration plants that were under observation were found to produce contaminated drinking water (Sohaila et al., 2020).

A review by Uddin et al., (2021) conducted to investigate the structures and mathematical techniques used in WQI models concluded that most of the models had broadly similar structures and that the finer details of the four main components varied greatly among the different models. Even though Water Quality Index is an effective tool for evaluating the overall water quality, the model parameters were generally chosen based on a few common water quality issues such as oxygen availability, eutrophication, health considerations, physical and chemical phenomena, and dissolved constituents. Even for several new WQI models it was found that they applied only general criteria, and they did not employ any radiological or hazardous parameters of water quality.

2.8 Human Health Risk Assessment

Health risk assessment involves evaluating available scientific data on the toxicology and exposure pathways of a substance, determining the level of exposure in the population, and assessing the potential health effects (USEPA, 1986). It is an effective tool used to understand the probability of adverse health effects in humans who may be exposed to chemical and biological agents in the environment (Zhang et al., 2022)

According to a study by Chen et al. (2016), infants are the most susceptible to drinking water contaminated with nitrate and fluoride. The study assessed the health risk of nitrate and fluoride contamination for rural populations in semiarid regions of Northwest China. Additionally, most of the samples had hazard indices greater than 1 (>1), indicating that while most samples provide little risk to adults, they may expose babies and children to non-carcinogenic risks through groundwater consumption. In a similar vein another investigation carried out in 2020 by Sohaila et al. determined that the arsenic hazard index was less than one in adults (9.80E+01 and 7.03E+01) and children (1.48E+02 and 1.06E+02) in Rawalpindi and Islamabad, respectively. However, the data showed that there were a risk and that people who were exposed to it, particularly children, were at high risk. In contrast, the findings of the Addo et al., (2013) study showed that, except for As, every other trace metal in the water samples showed potential toxicity. However, while considering the residential use of the well water, the calculation of non-carcinogenic risk carried out by this study indicated that negative health impacts might not arise. On the other hand, the chance of developing cancer in the long run may be increased by As exposure through water drinking.

A significant shortcoming identified in literature was the absence of specified exposure populations that were thought to be at risk. This can be improved when thorough descriptions of receptors are provided. It's interesting to note that although they are present in surface and groundwater, bacteria, pathogens, and radiological characteristics were rarely included in water research. Future studies that consider the danger related to chemical, radiological, and microbiological factors could therefore offer a more complete assessment of risk for populations that rely on uncontrolled source water.

2.9 Sanitary Inspection and Water Quality

World Health Organization defines sanitary inspection as an on-site inspection of a water supply to identify actual and potential sources of contamination. Sanitary inspection form is a short questionnaire use to determine the overall risk score of the water source (WHO, 2011). During sanitary inspection, each observed sanitary risk factor at the water source (e.g., borehole, spring) is scored with a "yes". The sanitary risk score for a particular water source is the number of risk factors at a water source. A sanitary risk score of zero indicates that the water source is at low risk of contamination and high-risk score is an indicative of water source at high risk. WHO recommended both sanitary inspection and water quality analysis to assess the risk of water source contamination because water quality testing alone is only a snapshot which provide limited information on the source of contamination, and it can miss important seasonal quality fluctuations. Although these tools are effective for risk assessment the relationship between these tools is poorly understood. The correlation between microbiological water quality and sanitary inspection is well established. Kelly et al. (2020) conducted a comprehensive evaluation and identified a substantial link between the microbial water quality and the sanitary risk score, which is used to reflect sanitary inspection outcomes. From the study, 21 (84%) used sanitary risk score to represent sanitary inspection, of which 12 (57%) of the studies found significant association between sanitary risk score and microbial water quality and 9 (43%) found no significant association. However, Luby et al. (2008) investigation on the quality of tube well water and predictors of contamination in three flood-prone areas in Bangladesh did not identify the most important causes of drinking water contamination in these communities using the sanitary inspection form. Kelly et al. (2021) used data from over 1000 hand pumps in 12 SSA nations to investigate the link between sanitary inspection and microbiological water quality in another study. The author compared scores and E. coli occurrence using the models described in published literature, and an alternative model that better reflects causal pathways of contamination. The results from the study validated the use of an alternative model, which reflects the causal pathway of water system contamination, and shows that the relationship between sanitary inspection and microbial contamination can be modelled more thoughtfully. The previous statistical model showed no significant correlation between sanitary risk score and E. coli occurrence. When sources, carriers and breakdown were accounted for in the alternative model, it demonstrated a weak but significant association between handpump breakdowns and E. coli occurrence. Furthermore, it demonstrates that some sanitary risk factors, especially barrier breakdowns, are more strongly associated with water quality than others.

2.10 Geographic Information Systems

A geographic information system (GIS) is a data creation, management, analysis, and mapping system for various kinds of information. GIS integrates location data with all kinds of descriptive information and links data to a map (Chang, 2008). Users may understand patterns, relationships, and geographic context more fully (Chang, 2008). Decision-making processes in a variety of sectors are supported by the visual outputs of geographical data that GIS can produce, such as maps and charts (Foote and Lynch, 1997). Planners may see and analyze data in a spatial context with the help of GIS, spotting trends and patterns that might not be apparent in conventional tabular data (Bugs et al., 2010).

Yeboah Adusei et al., 2021 using satellite imagery and machine learning models predicted and spatially mapped the quality of water of Owabi Reservior. The study concluded that S2 findings from all three models were more accurate than those from L8. The inter-sensor relative efficiency revealed that S2 performed 67% better than L8 on average in recovering WQPs from the Owabi Dam reservoir. When it came to RF, S2 performed best (R2.adj = 95–99%, RMSE = 0.02–3.03), whereas it performed worst (R2.adj = 55–9 1%, RMSE = 0.03–3.14). SVM produced findings for S2 that were comparable to those of RF, although with somewhat larger RMSEs (0.03–3.99). The estimated pH (bounds, alkalinity (179.60 mg/L), and total dissolved solids (39.19 mg/L) were all within acceptable bounds; however, the turbidity (33.49 mg/L) was higher than the reference values. The study recommended the use of S2 and RF models in surface water quality analysis. Likewise, Araya et al., 2022 modelled and estimated the population at risk as a results of Fluoride contamination of groundwater resources in Ghana using a set of geospatial predictor variables.

The research indicates that 15% of Ghana's land, mostly in the northeast, is highly likely to be contaminated with fluoride. Approximately 920,000 people, or 3% of the population, are at-risk, of whom 240,000 children aged 0 to 9 are thought to live in at-risk areas.

2.11 Land Use and Land Cover

The terms land cover and land use are the two main factors of land change. The term is usually used interchangeably but their actual meaning is not synonymous (Firdaus, 2014). The term Land cover refers to the physical characteristics of the land, such as vegetation, water bodies, bare soil, or artificial surfaces. Land cover reflects the natural or human-modified environment and can be influenced by various factors such as climate, topography, or land management practices (Yang et al., 2001). On the other hand, land use refers to the human activities that are carried out on a specific area of land, which can include agricultural, residential, commercial, industrial, or recreational uses (FAO, 2000). Changes in land use and land cover can impact water quality. Land use and Land cover change analysis has been used to determine the quality of water in some countries.

Tahiru et al., 2020 evaluated changes in land use and land cover (LULC) and their effects on local water quality in the White Volta Basin's Nawuni Catchment. For this investigation, satellite pictures of the Nawuni Catchment in the White Volta Basin were obtained using Landsat Thematic Mapper and Landsat 8 Operational land imager. The LULCC data showed a declining tendency for open savannah (14.7%) and water bodies (0.1%), but an increase in grassland/farmland (4.1%), settlement (0.1%), bare land (9.4%), and closed savannah (1.2%). Over the course of the study period (2007 to 2017), the study revealed a drop in total coliforms and an increase in turbidity and ammonia levels. Additionally, a positive correlation between LULC categories and water quality measures was found in the study, suggesting that LULCC are responsible for some of the changes in the local water quality. A recent land use and land cover study by Gbedzi et al., 2022 in Asutifi

North district in Ghana indicated Changes in land cover have the greatest impact on turbidity, while the least significant impact is on NH3.

2.12 Land Use/ Land Cover Change – The Role of Remote Sensing and Geographic Information Systems (GIS) Applications

Overall, remote sensing has proven to be a valuable tool in the monitoring and management of natural resources and land cover changes. The combination of various remote sensing techniques and datasets provides a comprehensive understanding of the spatial and temporal dynamics of land cover changes, which can inform land management decisions and policy development (Turner et al., 2007). The use of this tool provides an alternative for areas to be effectively map and monitored (Ozesmi and Bauer, 2012). Monitoring changes in urban environments, such as city growth and shifts in land use patterns, has been done through remote sensing. Furthermore, changes in surface water, groundwater, and snow cover have all been detected using remote sensing (Hausner et al., 2010). Changes in vegetation cover and productivity have also been tracked using satellite-based remote sensing data, which can have a big impact on the health of ecosystems and local climates (Joshi et al, 2014).

Themes of land cover are extracted by classification. Classification are means of sorting image pixels into their various land cover classes depending on their spectral pattern with the data (Adu-Poku, 2010). Supervised and unsupervised classification are the two main types of image classification methods. Unsupervised classification or clustering involves grouping pixels based on similarities in their spectral characteristics. This technique does not require any prior knowledge or training data and is helpful in identifying unknown or novel land cover classes (Kerle et al, 2004). On the other hand, supervised classification involves training an algorithm using a set of labelled samples, and then applying it to classify the entire dataset. This technique is useful when there is prior knowledge of the land cover classes of interest (Lillesand and Kiefer, 2014).

Principal component analysis (PCA) is a technique used to transform original spectral bands into orthogonal principal components. These principal components can be used to represent the variance in the data and can help in reducing the dimensionality of the data while retaining the relevant information. Hybrid classification involves combining different classification techniques to obtain more accurate results (Pearson, 1901).

Fuzzy classification involves assigning membership values to each pixel, based on its similarity to different land cover classes. This technique allows for pixels to belong to multiple classes, which can be useful in cases where areas have mixed land cover (Venkaleswaran et al, 2013).

In addition to these techniques, some studies have also used object-based classification, which involves segmenting the image into objects based on different criteria, and then classifying these objects based on their shape, texture, and other features. Overall, the choice of classification technique and dataset depends on the specific research question, the scale of the analysis, and the available data.

2.12.1 Accuracy Assessment

A helpful tool for assessing a classification algorithm or model's accuracy is an error matrix (Congalton, 1991). A number of accuracy measures, including overall, producer, and user accuracy, can be computed by comparing the classification results with the reference data (Story & Congalton 1986). These metrics can be used to pinpoint a categorization approach's advantages and disadvantages as well as serve as a roadmap for future research. In the error matrix, each row denotes a specific reference category, and each column denotes a specific classification category. The diagonal of the matrix represents the correctly classified samples, while the off-diagonal elements represent misclassifications (Congalton, 1996). Accuracy is obtained by averaging all accuracies for each class. The overall accuracy for a class is determined by the quantity of samples to be tested for that class (Jin et al., 2001). The kappa coefficient measures the degree of agreement between the classified map and the true map, considering the amount of agreement that could be expected by chance alone. It is a more robust measure of accuracy than overall accuracy alone, especially when classes are imbalanced or when errors are not uniformly distributed across the classes (Congalton, 1996). A kappa coefficient of 1 indicates perfect agreement, while a value of 0 indicates agreement no better than random. Therefore, kappa values closer to 1 indicate better accuracy of the LULC map.

$$\boldsymbol{K} = \frac{\boldsymbol{N}\sum_{i=1}^{r}\boldsymbol{X}_{ii-}\sum_{i=1}^{r}(\boldsymbol{X}_{i+}\mathrm{x}\,\boldsymbol{X}_{+i})}{\boldsymbol{N}^{2}-\sum_{i=1}^{r}(\boldsymbol{X}_{i+}\mathrm{x}\,\boldsymbol{X}_{+i})}$$

Where:

N is the total number of sites in the matrix, r is the number of rows in the matrix,

xii _is the number in row i and column I,

$x{+}i$ _is the total for row i, and

$xi{+}$ is the total for column i (Jensen, 1996).

CHAPTER THREE

METHODOLOGY

3.0 Introduction

Different study approaches were carried out to answer the research questions. This chapter, therefore, presents a detailed description of the topics and sub-topics such as a profile of the study area, study design and participants' allocation, study participants and the eligibility criteria. Others include sample size estimation, sampling procedures, data collection tools, and study variables. The data processing and analysis methods, descriptions, ethical considerations, study findings, and dissemination plan are also presented in this section.

3.1 Study Area

This study was conducted in Talensi District in the Upper East Region, of Ghana from August 2021 to February 2022. According to the 2020 census conducted by the Ghana Statistical Service, Talensi has a total population of 87,021 of which 43,849 are males and 43,172 are females. Talensi has a geographical land area of about 838.4 km^2. Almost 84.1% of the population live in rural areas and 15.9% live in urban areas (GSS, 2020).

Talensi District was originally part of the Talensi-Nabdam District until the northern part of the district was split off to create Nabdam District in 2012 (Abdul-Rahaman & Adusah-Karikari, 2019). The remaining part was renamed as Talensi District. It is currently one of the fifteen districts in the Upper East Region with Tongo serving as its district capital. It is bordered to the north by Bolgatanga Municipal, south by the West and East Mamprusi Districts, Kassena-Nankana District to the west and the Bawku West District to the east. It falls within the boundaries of latitudes 10º35" and 10 º 60" north and longitudes 0 º 31" and 1 º 05" west. The rationale for choosing this district for my research is that it is described as a semi-arid land, and it is one of the most vulnerable regions to climate change in Ghana. The region experiences increased weather conditions with more prolonged periods of drought (Cameron, 2011). The mean annual evapotranspiration is about 1750mm and exceeds rainfall. As any semi-arid land rainfall is highly variable, the mean annual rainfall is 95mm. As global temperature increases, rainfall patterns become less predictable. More intense rainfall is expected to increase erosion and less total rainfall may decrease the water flow, thus the reason for this research. The populace in the district relies on ground water through boreholes and open wells for mainly their potable water and other domestic and agricultural related water needs.

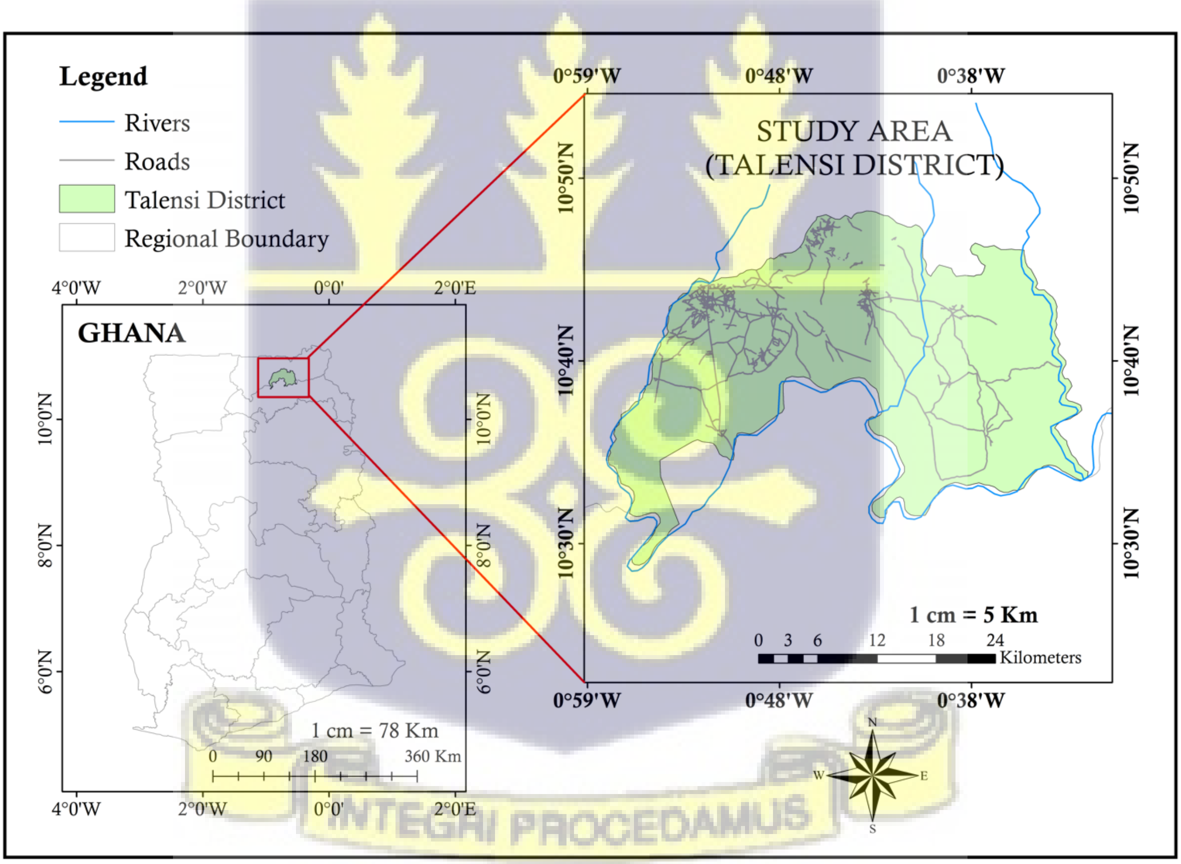


Figure 3: Map of the study Site

3.1.1 Climate

The district has a tropical climate with two distinct seasons, wet (rainy) and dry (no rain). The rainy season is unpredictable and runs from May to October each year with an annual mean of 95mm, while the dry season is long and stretches from October to April (GSS, 2020). Rainfall and temperature conditions in the district are highly variable. The temperature range in the district is from a maximum of 45 degrees Celsius in March to April and a minimum of 12 degrees Celsius in December (GSC, 2010). The annual precipitation ranges between 88mm-110mm. The mean annual evapotranspiration is about 1750mm and exceeds the rainfall (Peliga-Ba et al., 2004).

3.1.2 Vegetation

The district lies within the Guinea Savannah woodland in Ghana consisting of short widely spread deciduous trees and ground flora of grass which get burnt by fire or sun scorch during the long dry season (GSS, 2020). The most common economic trees are the Shea nuts, “dawadawa”, baobab and acacia (Nkansah, 2013). The district has three gazetted forest reserves covering a total area of 455.21 km^2.

3.1.3 Geology and Hydrogeology

The district is mainly covered by crystalline Precambrian rocks of the Birimian Supergroup, associated with granitoid intrusions, and a small patch of the Tarkwaian series. The south-eastern portions of the district are underlined with the Voltaian Supergroup and Kwahu-Bombouaka Group (Boateng, 1959). The presence of these rocks and geological formations can have a significant impact on the quality of water sources in the area. The impermeable nature of the rocks of the basement complex and Voltaian system, with little or no primary porosity characteristically, can make it difficult for water to naturally replenish and distribute through them (WRC, 2011).

Hence, the groundwater occurrence in the study area is primarily influenced by the presence of secondary porosities. These secondary porosities are caused by various geologic processes such as fracturing, faulting, jointing, shearing, and weathering. The aquifers in the study area are generally semi-confined and structurally controlled due to the development of fractures which give rise to secondary permeability (WRC, 2011). The district has two main types of aquifers, namely, the weathered zone aquifers and the fractured zone aquifers. The weathered zone aquifers are located at the base of the thick weathered layer, while the fractured zone aquifers are found at some depth beneath the weathered zone (Kortatsi, 1994; WRC, 2011). This information suggests that the hydrogeological characteristics of the study area are complex and varied making borehole yield dependent on the amount of rainfall they get in the district. Borehole yield within the weathered zone usually range from 0.41 m^3/hr to 29.8 m^3/hr (Dapaah-Siakwan & Gyau-Boakye, 2000), whereas yields in the fractured zones range be- tween 1 m^3/hr to 9 m^3/hr, but hardly exceed 6 m^3/hr according to Dapaah-Siakwan & Gyau-Boakye (2000).

3.1.4 Soil and drainage

The district's topography is characterized by scattered rock-outcrops and upland slopes with relatively undulating lowlands with gentle slopes ranging from 10 to 50 gradient at the Tongo areas (GSS, 2020). The district's soil is developed mainly from granite rocks, which are shallow and low in soil fertility, weak with low organic matter content, and predominantly coarse in texture (Kumasi et al., 2019). Erosion is a problem in the district. Valley areas have soil ranging from sandy loams to salty clays. They have rich natural fertility but are more difficult to till and are prone to seasonal waterlogging and flooding. The main river in the district is the -White Volta and its tributaries (GSS, 2010).

3.1.5 Socio-economic activities within the Talensi District

The quality and quantity of productive resources available determines the economic and social development of a district (GSS 2020). Agriculture is the main economic activity in Talensi District, it accounts for about 90% of the total employment. However, there are several light industries (large, medium, and small scale in nature) that provide employment opportunity for the people. The major crops grown are millet, sorghum, maize, rice, groundnuts, leafy vegetables, pepper, watermelon, and onion. Additionally, livestock such as cattle, sheep, goats, and donkeys are also reared in the area (GSS 2020).

3.2 Study Design

A cross-sectional study design, employing mixed-method (qualitative and quantitative) research approach was used in this study. Across-sectional study design is a type of observational study where the investigator measures the outcome and the exposure in the study participant at the same time (Pandis, 2014). Unlike in case–control studies (participants selected based on the outcome status) or cohort studies (participants selected based on the exposure status), the participants in a cross-sectional study are just selected based on the inclusion and exclusion criteria set for the study (Setia, 2016).

3.3 Inclusion and exclusion criteria for the study participants

3.3.1 Inclusion criteria for the study

- Adults responsible for fetching and managing water in the house.
- People who are permanent residents (have lived at least more than a year) in the selected communities were eligible.

- Community representatives who have lived in the selected community for more than a year.
- People who could communicate in English or local dialect "Frafra" were included
- District Office staff who have been working in the district office for more than a year.
- Functional water sources used by residents were selected
- Households that have water storage facilities
- Stored water in the households was also selected for water quality analysis.

3.3.2 Exclusion criteria for the study

- Adults who were not responsible for fetching and managing water
- Subjects who have stayed in the community for less than a year were not included.
- Members who could not communicate in neither English nor their local dialect "Frafra" in the study area were also not included.
- Households without water storage facilities were excluded.
- Participants who were unable to respond due to severe physical speech challenges that could affect their ability to consent and willingness to participate in the study were also not included.
- Broken and non-functional water sources were not included
- Sources that residents do not use were not included

3.4 Quantitative and Qualitative Study Population

3.4.1 Study population - quantitative study component

Household heads as well as women aged above 18 years who were responsible for water collection and management and had stayed in the community for at least a year were selected. The same respondents were selected for both survey seasons.

3.2 Source and study population - qualitative study component

Heads of Department in charge of the provision and management of water in the district were purposively selected for the qualitative data. Community leaders like chiefs and Assembly members also served as respondents.

3.5 Data Collection Techniques and Tools

3.5.1 Data source

Primary data were obtained through interviews and observations.

1. A structured questionnaire adopted from the Ghana Demographic and Health Survey (GDHS, 2014) and Multi Indicator Cluster Survey, (MICS, 2018) was used to collect primary data on households' source of water, storage and treatment.
2. A modified appraisal form adopted from WHO was used to appraise water sources and household water storage. It was used to collect data on hazardous events around the various water supply and households' hygiene practices.
3. Qualitative data was also collected through Key Informant Interviews and Focus Group Discussions. FDG and KII discussions helped to source data and information from stakeholders in a structured discussion. Focus group and Key informant discussions revealed divergent perspectives at the same time as allowing in-depth discussion.
4. Water samples were also collected for analysis at the laboratory. Physicochemical Properties pH, EC, TDS, Temperature. Microbial Contaminants Total Coliform, E. coli, Fecal Enterococci, Salmonella spp., Shigella spp., and Chemical Contaminants Fluoride, Nitrate, Arsenic, Lead, Mercury was analyzed.
5. GPS coordinates of water sources, households and possible sources of contaminants were collected using Garmin GPSMAP 62stc device.

Secondary data were obtained from

1. United States of America Geological Survey (USGS). Two Landsat ETM+ and OLI images data acquired from the USGS website (http://earthexplorer.usgs.gov/) in September 2021, and February 2022 were selected for this research. These images had cloud-free weather condition and covered the whole of Talensi District.
2. Gridded population data from Ghana Statistical Service (the data was produced using the 2021 population and housing census data) (100m resolution Yankyey et al., 2024).
3. Environmental data on temperature and rainfall was obtained from the National Aeronautics and Space Administration (NASA). Daily mean rainfall mm and temperature°C data for the month of September, 2021 and February 2022 were used. The data was in an excel format.

3.6 Household sample size estimation

3.6.1 Calculation of quantitative study sample size.

Power analysis

The sample size for the study was based on the modified version of Cochran's formula shown below:

$$n = DEFF \times \frac{Z^2_{1-\frac{\alpha}{2}}p(1-p)}{[e]^2}(r+1) \ldots\ldots(1)$$

$$n = 1.2 \times \frac{1.96 * 0.5(1-0.5)}{(0.05)^2}(0.022+1) \ldots\ldots(1)$$

$$n = 240$$

where n is the required sample size (number of study participants), $Z_{1-\frac{\alpha}{2}} = 1.96$ is the standard normal variate at type I error $(\alpha) = 5\%$ $p = 50\%$ is the anticipated proportion of study participants who have no access to improved water source in the rural communities in the Talensi

District, $e = 5\%$ is the margin error associated with the point estimates. $r = 2.2\%$ is the individual level non-response rate. This study will used a design effect (DEFF) of 1.2 similar to what has been reported in the DHS.

Substituting the parameters in equation 1, the total number of participants required for the study is 240. To determine the number of households required to find 240 older adults, it was assumed that assumed that $P_{\text{older (18+)}}$ 40% of the households would be adults aged 18+ with an average household size of 5.1. r_h -none response rate.

$$\#Households = \frac{n * (r_h + 1)}{H_{size} \times P_{older(18+)}} \ldots\ldots\ldots(2)$$

$$\#Households = \frac{240 * (0.022 + 1)}{5.1 \times 0.40} \ldots\ldots\ldots(2)$$

$\#Households = 120.24$

Therefore, estimated number of households is 120.24

3.6.2 Sample size for qualitative study

The qualitative study sample was determined based on information saturation during key informant interviews (KIIs), and Focused Group Discussions (FGDs). Overall, twenty-two participants were involved in the qualitative component of this study. Of this, four FGDs which comprised of eight to twelve discussants (40 participants) were held at selected sub-districts. Ten (10) KIIs were conducted for local leaders and Heads of Department.

3.7 Sampling procedure for household survey

A multistage stratified cluster sampling method was used to select study participants for quantitative study.

3.7.1 Multistage stratified sampling method

The district was divided into two subgroups or strata (Mining and non-mining areas). Within each stratum two mining communities were selected (Gbane-Kejetia and Gbane-Obuasi) and two communities in non-mining areas (Balungu and Shia) were selected. Three (3) enumeration areas enumeration areas (EAs) were selected independently in each stratum. The second stage involved the selection of a fixed number of 10 households per cluster selected from the newly created households listing by the current population housing census. This process yielded 120 households in the 4 communities. These 120 households were selected for both survey season, August/September 2021(rainy season) and January/February 2022 (dry season). The participant information sheet was read to household member to enable them to give their consent to participate in the research. The household head and one elderly woman or girl in the household were recruited for the study. Questions were asked in their local dialect Frafra and their responses were recorded directly onto a tablet using Kobo collect software.

3.8 Study Variables

The study variables were made up of the dependent and the independent variables. A brief description of how the composite variable is constructed is available in sub-section.

3.8.1 Primary Dependent Variables for Objective One

The outcome of interest in this study was "households' access to improved water". This was generated as a binary variable (coded as 1 if the household had access to an improved water source and 0 if it had no access to an improved water source). The definition of improved water adopted was that of the WHO/UNICEF Joint Monitoring Programme (JMP) 2017. Improved sources are those that by the nature of its construction and design, is likely to protect the source from outside contamination, in particular from faecal matter.

3.8.2 Independent Variables for Objective One

Potential determinants of households' access to improved water sources were identified during literature review and these included geographic, demographic, and socio-economic characteristics. Geographic (mining and non-mining area), and socio-economic characteristics of households were assessed based on an asset-based wealth index constructed using the Principal Component Analysis (PCA), a method which was classified into wealth tercile, 1) poor, 2) middle and 3) richer (GDHS, 2014). Ethnicity (e.g., Frafra, Akan,), sex, and educational level were based on the characteristics of the head of the household. Educational level was divided into four groups: 1) Tertiary, 2) Secondary, 3) primary, and 4) none. Other potential explanatory variables e.g., household location (Mining versus non-mining) price of water and time taken to fetch water, and environmental variables like temperature and rainfall were also included.

3.8.3 Variables for Objective Two

Water quality parameters pH, Temperature, Electrical Conductivity, Total Dissolved solids, Fluoride, Nitrate, Arsenic, Lead, Mercury, Total Coliform, Fecal Enterococci, E. coli, Shigella spp., Salmonella spp.

3.8.4 Variables for Objective Three

Water facilities, possible source of contaminates, water quality parameters.

3.8.5 Variables for Objective Four

Vegetation, water, bare land, built-up, water quality parameters, populations.

3.9.1 Sampling procedures for qualitative study

A pragmatic qualitative research approach was employed to explore communities' access to improved water, water treatment and water uses. A purposive sampling method was employed to select study participants for the KIIs and FDGs from Talensi District Officers and community representatives. Stakeholders such as local politicians and local leaders were also involved.

Sampling procedure for water quality analysis:

3.9.2 Key Informant Interviews

KIIs were conducted with the core heads of the various institution at the district assemblies (MMDAs) and other key stakeholders to determine their role in providing improved water sources in the district and information on what the various stakeholder have done over the past 10 years to increase household access to improved water sources. Head of Environmental Health Department, Water and Sanitation Unit, Works Department and Planning Officer at the District Assembly were interviewed.

3.9.3 Focus Group Discussion

FDG's were held among 8 to 12 discussants per group to determine access to improved water sources in these communities, and the changes that have occurred over the past decade. One community in the mining area (Gbane-Obuasi) and one non-mining community (Balungu) were selected for the FDG. The moderator (Research Assistant) led the discussion by asking questions and probing answers using the topic guide. And a translator then translated the questions into their local dialect (Frafra). Serious attention was given to capturing necessary information using voice recorders, and note taking during the discussions. It took 45 to 60 minutes to conduct one FGD. Myself and another research assistant were taking notes during the discussion.

3.10 Sampling procedures for water analysis

3.10.1 Sanitary Inspection

As part of the baseline data collection, the study employed sanitary inspection tool to evaluate and identify actual and potential sources of contamination around water facilities. This is a powerful and generally applicable tool for the risk assessment of water supply systems. It is widely used in small water supply settings to support the identification and management of high-priority risk factors. The tool was used to identify hazardous events around the various community water supply systems.

The team visited each water supply system (from 18th August, 2021 to 18th September 2021 and 15th January, 2022 to 15th March 2022) and also and inspected the presence of observable source of contamination and conditions that may lead to the introduction of hazards into the water system. Each main source of water and household water storage was appraised using the WHO water sanitary inspection form (WHO, 2024). Sanitary inspection forms typically make use of standardized questions. It contains a systematic checklist of a limited number of specific questions. These checklists address the most basic and common factors that may lead to contamination of the water system.

This was done before collecting water samples for analysis. For every water system assessed, a sanitary risk score was calculated based on these observations and classified with a sanitary score ≤ 3 as low risk, 4–5 as medium risk, 6–7 as high risk, and 8–10 as very high risk (WHO, 2024). Information on reported tubewell age and depth, and household sanitation infrastructure and practices, including observed presence of an improved latrine, and reported location of defecation and feces disposal for children < 2 years of age are some of the questions in the tool. Two reservoirs and streams were not appraised with the sanitary inspection because the WHO and UNICEF do not have a standardized questions for such sources but in this study, the researcher looked for possible sources of contaminants near these sources

3.10.2 Selection of Water Sources

From both the mining and non-mining communities, functional water systems and household water were randomly selected (100 water sampling points). The method for sourcing water points was done by interviewing some key informants from all the communities. They helped in identifying functional water sources in the communities. In addition to household water, the sources of water that were identified as functional water systems that supply water to the communities in Talensi district included boreholes, rainwater harvesting systems, streams, and hand dug wells.

3.10.3 Sampling Frequency

Reconnaissance sampling involving the selected boreholes, rainwater, some surface water resources, and household water was carried out in September 2021rainy season and February 2022 dry season. Subsequently, sampling was carried out during the rainy and dry season. Thirty-four main water points were sampled, and 66 households water samples were collected for laboratory analysis. 50 during the rainy season and 50 during the dry season. In total, 100 water samples were collected.

3.10.5 Water Quality Testing

In all a subset of 34 main sources of water and water from 66 households that participated in the survey questionnaire were selected to participate in the second phase of the study. Sixty-six (66) households were selected based on their geographic area (mining and non-mining areas). Seventeen (17) main sources of water and 32 household water samples were randomly selected for sanitary inspection and water quality analysis for each survey season.

3.10.6 Method for Water Sampling

All water samples were collected into IDEXX branded sealed Sterile, Rigid, and Clear Plastic screw-cap bottles with 100 mL mark. These bottles contained sodium thiosulfate powder to neutralize the effect of Chlorine in the water. A small airspace of approximately 1/4 inch at the top of the sampling bottles was always left to facilitate proper and adequate mixing of the samples prior to every analysis.

3.10.7 Equipment and Supplies Used for Sample Collection

1. Sample collection bottles

2. Water-Bacteriology lab notebook

3. Pen with waterproof ink

4. Ice chest with ice packs

5. Garmin GPSMAP 62stc device

Water sampling

Sampling From Boreholes: The sprout of all the boreholes were flamed with spirit-soaked cotton wool for about 3-5 minutes and water was pumped out from the borehole under high pressure for about 3 minutes and samples subsequently taken aseptically under low pumping pressure into sterile sample collection bottles. It was ensured that the Chlorine neutralizing thiosulfate powder in the sterile sampling bottles was not emptied or rinsed out of the sampling container when samples were to be used for microbiological analysis. Samples for physicochemical parameter analysis were taken in sterile bottles without the Chlorine neutralizing thiosulfate powder in the sterile sampling bottles.

Sampling from non-mechanical Hand-dug wells (Protected/non-protected): Water samples from the wells were drawn/taken by using the container that was often used to draw water from the wells for domestic use by the household(s). Water samples were then aseptically transferred, in duplicates, into sterile sampling bottles from the water drawn from the well.

Sampling from other surface water sources (rivers and ponds): Grab or spot or snap` samples were taken in duplicates into sterile sampling bottles with or without Chlorine neutralizing thiosulfate powder depending on the target parameter to be analyzed. The sampling bottles were plunged about 20cm mouth-down facing the water current and the water samples were subseq\

3.10.8 Sample Packaging, Transport and Storage

All water samples collected were well packaged in an ice chest cooler with ice packs and transported to the laboratory and stored at 6 ^{0}C and inoculated within 24 hours of sampling.

3.11 The Membrane Filtration Method Used in Culturing Bacteria

3.11.1 Step-by-step Procedure

1. Water samples were collected aseptically.
2. The appropriate culture medium was selected with respect to the target microorganism.
3. Sterile forceps were used to remove the membrane filter (47mm in diameter, 0.45µm, made from cellulose ester) from the case and placed into the filter assembly.
4. The pouring lip of the sample container was flamed before pouring the sample into the funnel.

Non-portable and turbid water samples which were suspected to produce confluent colony growths or colony growths of more than 200 cfu/100ml because of the floods were diluted before filtration was done.

5. The vacuum pump was turned on and the appropriate sample volume was allowed to draw out completely through the filter paper.
6. The forceps were then flamed to remove the membrane filter from the funnel.
7. The filter paper was then placed in the Petri dish containing the appropriate medium.
8. The Petri dish was then incubated at the proper temperature and for the appropriate period.
9. Discrete colonies formed were then enumerated and calculated using the formula.
10. Bacterial colonies (cfu) per 100 mL = Bacterial colonies counted all divided by the quantity (mL) of sample used × 100.

3. 11.2 Target Organism, Medium used and Growth Characteristics

1. Colony appearance of *E. coli* on Brilliance *E. coli* / Coliform medium incubated for 24 hours at 37 ^{0}C: Purple colonies.
2. Colony appearance of *Salmonella spp* on X.L.D Agar incubated for 24 hours at 37 ^{0}C: Red colonies with **black centers**.
3. Colony appearance of *Shigella spp* on X.L.D Agar incubated for 24 hours at 37 ^{0}C: Red colonies.
4. Colony appearance of *Faecal enterococci* on Enterococci - Agar incubated for 24 hours at 37 ^{0}C: Red colonies.
5. Colony appearance of Faecal Coliforms on m-FC broth w/o resolic acid incubated for 24 hours at 44.5 ^{0}C: **Blue colonies.**

3. 11.3 Media Preparation

The media was prepared based on the manufacturer`s instruction.

3.11.4 Method used for determining the turbidity of water samples

A calibrated HACH turbidimeter was used to assess how turbid the water samples were.

10mls of each sample was pipetted into a glass vile and measured using the HACH turbidimeter.

3.11.5 Method used for determining the ph of water samples

1. The Mettler Toledo Five Easy pH Meter was used to determine the pH of each water sample.
2. The pH meter was calibrated using pH 7 and pH 10 standards.
3. After the calibration, the probe of the pH meter was suspended in 200mls of each water sample and readings were recorded.

3.11.6 Method used for determining the electrical conductivity of water samples

1. The Mettler Toledo Five Easy conductivity meter was used to determine the conductivity of the water samples.
2. The meter prior to use was calibrated using conductivity standard 1413 µs/cm
3. The probe of the calibrated conductivity meter was inserted into 50 ml of each water sample at a time and the conductivity values read off and recorded in µs/cm. The probe rinsed with deionized distilled water and dried with blotting paper after each measurement.

3.11.7 Method used for measuring nitrate as nitrogen in water

1. Nitrate: Ion-Selective Electrode (ISE) method was used. It employed Thermo-Scientific Orion 9707BNWP Sure Flow Combination Nitrate Ion Selective Electrode (ISE) connected to Thermo Orion four-star pH meter.
2. The meter was calibrated using 20mL each, of 1 mg/l, 10 mg/l and 50 mg/l Nitrate standards solutions prepared from a 1000 mg/l stock. They were buffered with Nitrate Interference Suppressor Solution (NISS- Thermo Scientific 930710).

3. 20mL from each of the samples was then buffered with 20mL of a Nitrate Interference Suppressor Solution (NISS)
4. Measurement of Nitrate as Nitrogen was then determined and recorded in mg/l.

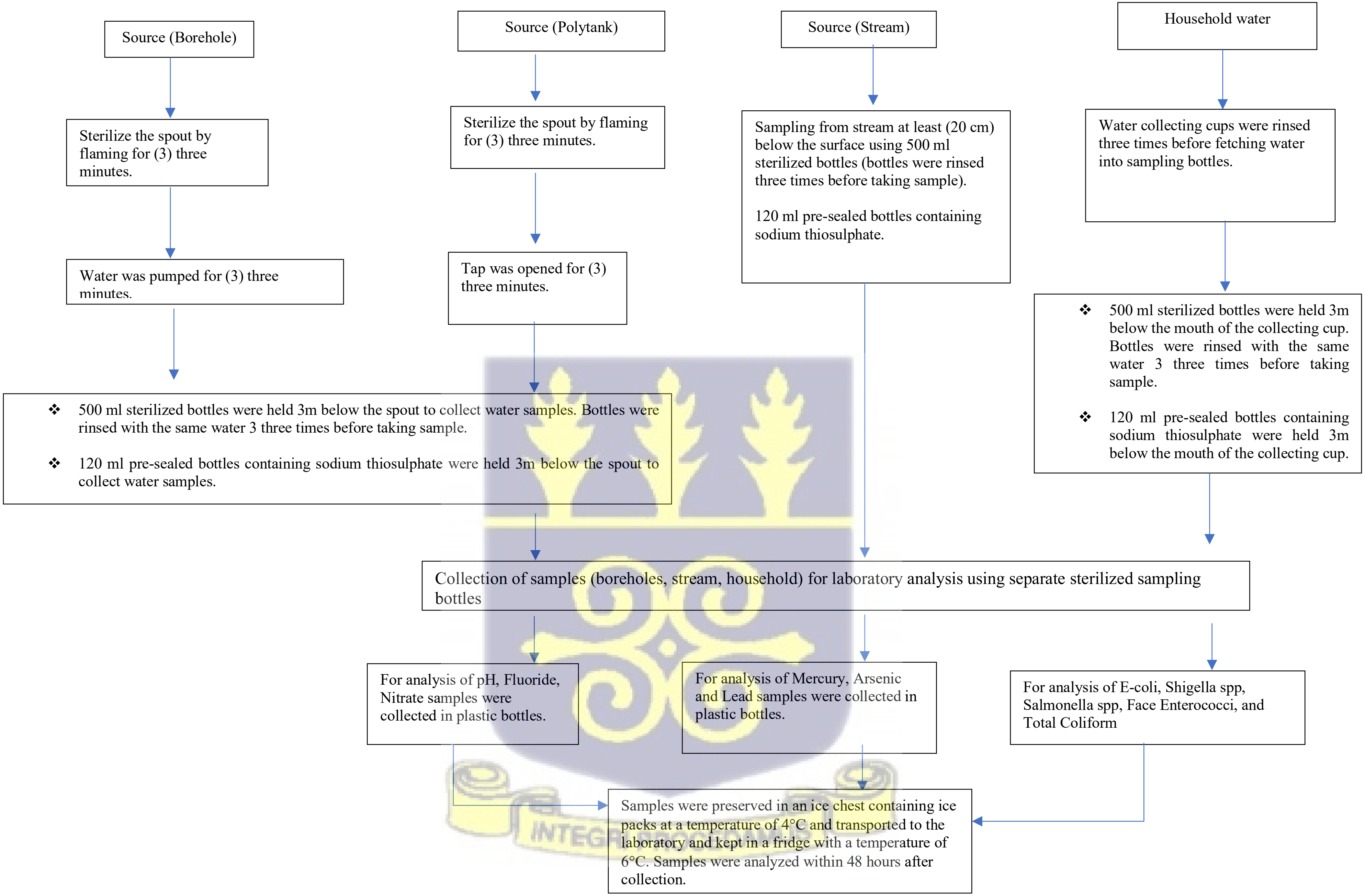


Figure 4: Flow chart for ground, surface and household water sample collection, showing the steps involved in sample collection, sample preservation and

3.11.8 Method Used for Determining Trace Metal in By Water Samples Electrothermal Atomic Absorption Spectrometry

Table 1: List of elements, Detection limits at element specific wavelengths are reported in it.

Parameters	**Wavelength (nm)**	**MDL (µg/l)**	**Cleaning gas**
Arsenic	193.7	0.1	Argon
Lead	283.3	0.05	Argon
Mercury	253.7	0.0001	Does not require a cleaning gas

This study employed the Flam Atomic Absorption Spectroscopy (FAAS) model AA-7000 Shimadzu. Standards were prepared by serial dilution of single element standards purchased from vendors that provide traceability to National Institute of Standards and Technology (NIST) standards. For quality assurance, standards were run after ten samples. Standard solutions of As, Pb and Hg were prepared to standardize and calibrate the instrument. The detection limits of the instrument for the analyte of interest are depicted in the above table.

3.12 Geospatial Assessment

Germin handheld GPS eTrex 10 was used to take coordinates and elevation points of main sources of water, households, and the possible source of contamination such as sanitation facility, tailing dams and farms. Data were collected as latitudes and longitudes referenced to the WSG 1984 datum. A GIS thematic layer was generated for the investigated wells and then attributes added that captured all the measured chemical, biological and physico-chemical analysis. This was used to generate an interpolated map of water contaminates using IDW interpolation method. The map showed areas with good and poor water quality as well as areas with high pollution and the population at risk.

3.13 Land Use/Land Cover Change Assessment

3.13.1 Data Acquisition

The study used Landsat data from two different years covering September 2021 and February 2022. All the acquired data were obtained from the USGS Earth Explorer (https://earthexplorer.usgs.gov/). The data selected were two Landsat ETM+ and OLI images data. These images had a cloud-free condition and covered the whole of Talensi District. The datasets were obtained in June 2021. The other data used in the study include the district boundary vector data of Talensi, river bodies, towns, and forest reserves, which were obtained from the Remote Sensing and Geographic Information Laboratory (RSGIS Lab). The importance of mapping the various land use is important to identify the impact of land use on water quality (groundwater and surface water).

3. 13.2 Data and Image pre-processing

Table 2. Landsat ETM+OLI used in this study.

RS DATA	DATE ACQUIRED	RESOLUTION	SOURCE
LANDSAT 7ETM+	September, 2021	30m	USGS WEBSITE
LANDSAT 9 OLI	February, 2022	30m	USGS WEBSITE

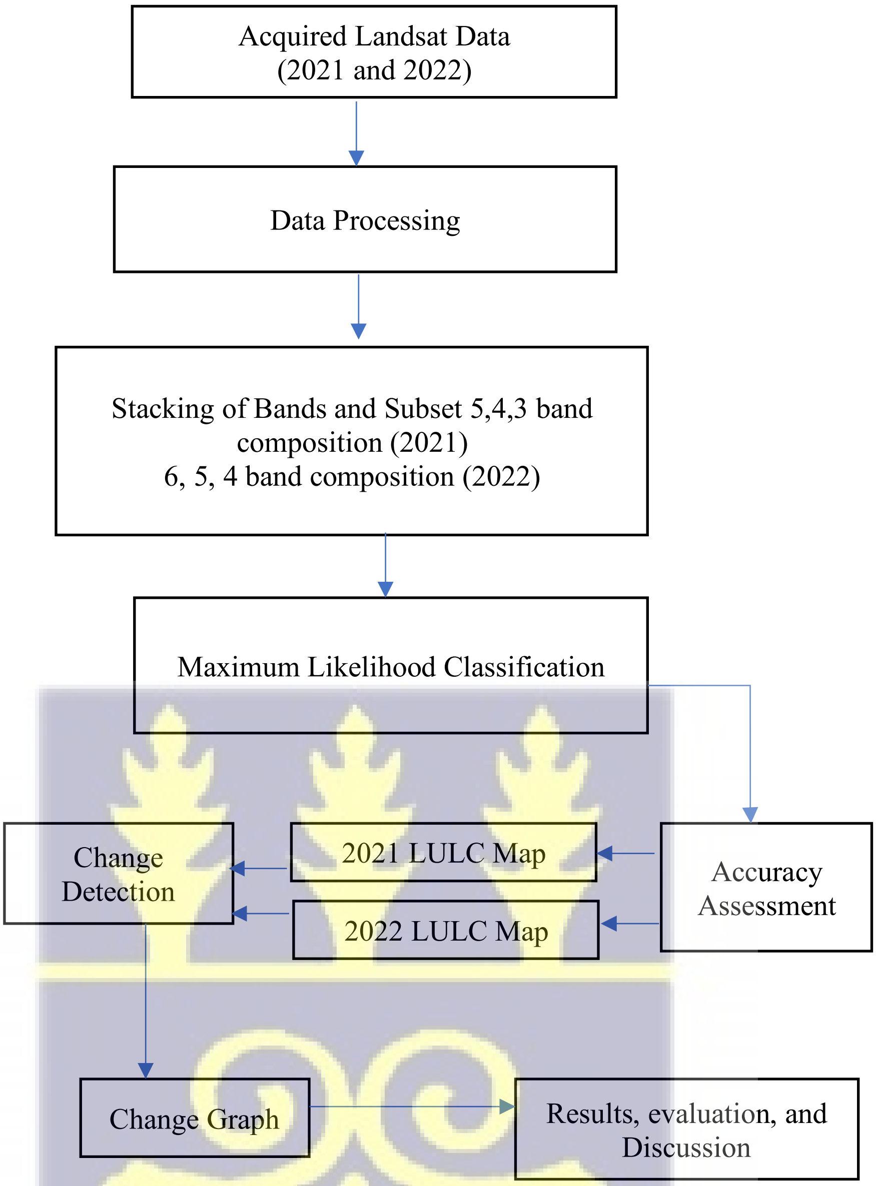


Figure 5: Schematic diagram showing the processes used to derive the LULC in Talensi District

3.13.3 Image Enhancement

To improve the visual interpretation of the images, which is extremely important, all the individual subset images were subjected to image enhancement techniques. Among all the image enhancement techniques that are available, the Histogram Equalized Stretch (HES) technique was chosen to enhance the images. Using this technique, digital values were plotted as a histogram to show the frequencies of occurrence of each of the digital values. More display values were assigned to the frequently occurring portion of the histogram (and stretched within that range), while less range was assigned to the less occurring portion, in doing this, details in frequently occurring values were enhanced relative to those of the original image.

3.13.4 Pre-Processing

To achieve an accurate change detection, the multi-temporal images must be pre-processed both geometrically and radiometrically to correct errors arising from imaging sensors, atmospheric effect, and earth’s curvature. Pre-processing operations, sometimes referred to as image restoration and rectification are intended to correct for sensor and platform specific radiometric distortions of data. The pre-processing methods that were performed on the two images include radiometric corrections such as calibration, dark object subtraction, and image enhancements. Also, geometric corrections were made on both images.

3.13.5 Image Classification

Supervised classification with the Gaussian maximum likelihood algorithm was used to monitor the LULC change and classify the images into the various land cover classes. Control points of the various land cover types were obtained from Google Earth (September, 2021 and January, 2022). Training sites were digitized for vegetation, built-up areas, bare land, and water. These four training sites which were used in this study were named and saved in the Signature Editor using ArcGIS Pro.

After generating the signatures, the next stage of the classification process was the classification itself. Using the supervised classification tool in ArcGIS Pro, the 2021 and 2022 classified images were then classified into four types. The parametric rule used in the classification was the Maximum Likelihood Algorithm (MLA). The MLA classified the images according to the covariance and variance of the spectral response patterns of the pixel. Thus, the individual images were classified into four main distinct land cover classes namely urban/built-up, vegetation, bare lands, and water. The table below is a description of the various land cover classes.

Table 3. Classification Scheme

CLASS LEVEL	**DESCRIPTION**
Urban/Built-up	This comprises of areas of intensive use with much of the land covered by structures. Included in this category are cities, towns, villages, highways and transportation, power, and communications facilities.
Vegetation	This was made up of Deciduous Forest Land, Evergreen Forest Land, and Mixed Forest. Consecutive layers of trees extend over each other to create a continuous linkage of either the same or the different species.
Water body	This included the rivers, lakes, open dams, and all water bodies expose to the surface from sky view.
Bare land	This includes the exposed sand, rocks, newly cleared farmlands, and over grazed areas.

3.13.6 Accuracy Assessment for Image Classification

For the two classified images, a confusion matrix was created using a laydown process in ArcMap Pro A total of 200 validated samples for the rainy season and 215 validation samples for dry season were gathered. Each had their corresponding validation samples from google earth. The steps involved are as follows:

First, determining reference points or ground truth points. Second, ground truth point conversion from vector to raster data. The process of creating a confusion matrix comes last, after which the raster data is combined and the image is classified.

3.14 Data Quality assurance

Mostly, quality assurance is carried out to minimize the threats of internal and external validities of the study findings to assure the quality of data, training, tool validation, pretest, supportive supervision, and other series of activities were carried out at pre-data collection, data collection, period, and post data collection.

Pretesting provides an opportunity to identify any problems with the study materials or procedures and adjust before starting data collection. Supportive supervision during the data collection period helped ensure that the data collectors followed the protocols and procedures correctly.

Post data collection, and quality control measures were used to check the accuracy and completeness of data collected. These measures can include data cleaning, data analysis, and outlier detection, and other quality control checks, depending on the study design and data collection methods. For the Laboratory work, UV light was used to disinfect the fume hood, the room was sprayed with 70% Alcohol. Distilled water was used as blanks and reference standards were used for quality assurance.

3.14.1 Data collectors

The data were collected by 6 people comprising 3 Senior High Secondary teachers, and 2 graduate students and 1 Water Quality Laboratory Officer. The research assistants were trained on data collection and ethical issues in research. Most of the research assistants were from the community and could speak the local language. Two supervisors with a master's qualification in laboratory work and previous experience in DHS, MICS and Census surveys were assigned to coordinate and support fieldwork.

3.14.2 Data collectors (field assistants) training

A day's training sessions was organized for research assistants (data collectors and supervisors) by the principal investigator. This was aimed at focusing on the purpose of the study, data collection procedures, interview techniques, sampling methods, data quality assurance, confidentiality and other ethical issues of data collection were important areas covered in the training sessions. This was to ensure that all the research assistants were well-informed about the research objectives and how to conduct the study in a standardized manner.

3.15 Data processing and statistical analysis

3.15.1 Data processing and or coding

Regular quality checks were done to ensure that the data collected was accurate and reliable. Independent and dependent variables were pre-defined (coded, labeled and assigned values) in the data entry template. The survey questions were asked in their local dialect (Frafra), and the responses (*n*= 240 in both seasons) were equally obtained in their local dialect (Frafra). Responses were recorded directly onto a tablet using Kobo collect software.

3.15.1.2 Coding of Households access to improved drinking water

Households' access to improved water sources was generated as a binary variable (coded as 1 if households had access to improved water source and (0 if they had no access to improved water sources) (JMP, 2017).

3.15.3 Descriptive data analysis

The data analysis was carried out using STATA version 16. Data cleaning was performed by computing frequencies of all variables to explore outliers and normality. Descriptive statistics was applied to determine the prevalence (proportion for categorical variables) or mean, median and standard deviation of continuous independent variables. Descriptive and logistic regression analysis was carried out to address all objectives of the study, and mainly objective 1 aimed to determine factors associated with households' access to improved water sources. For Objective 2 and 3, descriptive statistics were conducted, and three models were employed.

3.15.4 Inferential Statistics

To compute the effect size and to examine the relationship between the dependent and the independent variables to answer Objective 1, 2, 3 and 4 inferential statistics methods were applied.

Logistics regression was performed to determine households access to improved water sources and factors associated with it. The overall change in access to improved water sources in both survey seasons was determined. Non-parametric test Two-sample Wilcoxon Signed-Rank Test was used to explore the difference in water contaminates during the rainy and dry seasons as well as the main source of water and households. Three models were used to determine water quality and health risk assessment. Surface interpolation was used to achieve spatial modelling and prediction of water quality. The goodness of fit model was run to test if observed data aligns with what was predicted.

3.15.4.1 Logistic Regression Analysis

The aim of conducting this analysis was to address Objective 1 that sought to identify the relationship between households' access to improved water sources and independent variables. Both crude and adjusted odds ratios were calculated. Adjusted odds ratio was added because each added independent variable could increase or decrease crude OR, producing higher or lower AOR. The final adjusted model was run to identify factors associated with the outcome variable by controlling for confounders.

3.15.4.1 Wilcoxon Signed-Rank Test

Wilcoxon Signed-Rank Test which is a nonparametric test was used to address objective 2. It was used to compare outcomes between two independent groups, that is the difference in water pollutant levels at the household and at the main source as well as the difference in water pollutants during the two survey seasons.

Statistical tests were performed on their rank values (Wilcoxon Signed-Rank Test) with significance at the $P < 0.05$ level.

3.16 Qualitative data analysis

The qualitative study synthesis was carried out mainly to complement objective 1 of the study. In addition, the qualitative study contributes to objective 1 to complement the quantitative findings. The details of the qualitative data management describe on the following sub-sections.

3.17 Interpolation

The study employed Inverse Distance Weighted (IDW) to achieve objective four. IDW interpolation works on the assumption that things which are closer to each other are more alike than those which are farther apart. In IDW, interpolation weights are calculated as a function of the observed sampling point and the prediction point (Gunnink and Burrough 1996). Thus, greater weights will be assigned to the points which are closer to the targeted location. The formula for IDW is

$$Z_p = \frac{\sum_{i=1}^{n}\left(\frac{Z_i}{{d_i}^p}\right)}{\sum_{i=1}^{n}\left(\frac{Z_i}{{d_i}^p}\right)}$$

In this equation, Z_p is the p^{th} unknown value and n is the number of points that are taken to obtain the unknown value. The known value is *i,* where $d^p{}_i$ is the distance between the i^{th} known value and the p^{th} unknown value.

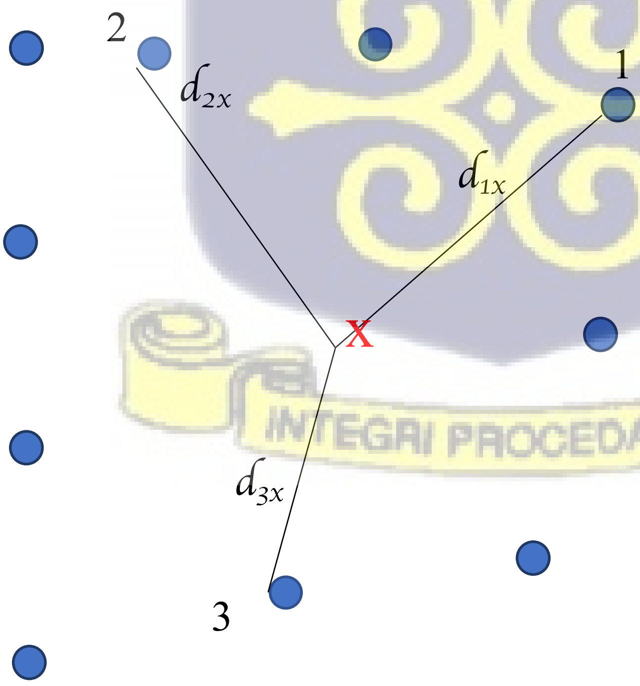


Figure 6: Illustrates how the IDW interpolation works.

The figure indicates that a value at position *x* will be determined from sampling points 1, 2, and 3, with the distances to *x* point being *d1x*, *d2x* and *d3x*. Using the equation 2, each respective weight will be calculated and then the value at position *x* will be determined using equation 1.

Using the 2020 population data the study identified the total population living in areas with groundwater fluoride levels exceeding 1.5 mg/L (GSS, 2021). All the people in these areas rely on groundwater for their daily water needs. The potentially population affected was estimated by multiplying the pixel's ground water-consuming population by the probability of having a high risk of fluoride contamination as described by (Podgorski & Berg, 2020; Araya et al., 2022).

3.18.1 Transcription of interview

Transcription was done for the collected qualitative data from side to side playing and re-playing the voice recorder and referring to the summary notes taken during interviews or FGDs. The voice audio recorder was listened to several times as much as possible at very quiet place. It was transcribed verbatim and independently by research assistants and the principal investigator. The transcribed qualitative data were translated from the local language (Frafra) into English.

Translation of the language was done according to public health research (Braun & Clarke, 2006; Pitchforth & Teijlingen, 2005).

3.18.2 Coding of the Transcriptions

The qualitative analysis package NVivo 12 was used to code all the transcripts. Coding aimed to capture the range of views on households' water access, households' sanitation access, challenges and facilitators to household water access, changes in households water access over the past 10 years, the role of district office in providing water and sanitation facility in communities. Corresponding to the themes and subthemes, parent and child nodes were constructed according to the flow of interviews and FDGs.

3.18.3 Identification of Themes

Thematic analysis approach was employed for qualitative data management (Braun & Clarke, 2006). The transcribed qualitative data from interviews and FDGs were arranged into thematic areas. Similar ideas were read and re-read for better understanding of the transcribed data. They were then, color coded, and merged accordingly. The participants' quotes were narrated and presented using the participants' code.

3.18.4 Arranging the Findings

NVivo version 12 was used to analyze qualitative data. Qualitative data arrangement activities were performed. Node was then exported to Microsoft Word for manual arrangement of the text. Similar ideas were color coded and merged manually. The findings were presented in text and visual illustrations.

3.18.5 Treating Missing Values

If no organism was detected because the water sample genuinely has no organisms, it would likely be classified as Missing Not at Random (MNAR), as the absence of data is directly linked to the true value (organism count). The missing values was kept in the dataset but treated as zeros. Replace the missing values with **zero** if the absence of detected organisms truly reflects the absence of organisms in the sample.

3.19 Water Quality Index Model

To compile data on water quality and assess the quality of the various water sources, the study used the Canadian Council of Ministers of the Environment Water Quality Index model (CCME WQI). The British Columbia Ministry of Environment, Lands and Parks created the index upon which the CCME WQI is based (Rocchini and Swain 1995). The CCME WQI was used to compare water quality between sites as well as monitor changes in water quality over time at a single site. Each of the three components that comprise the CCME WQI was computed following the definition of the body of water, the period, and the criteria and recommendations. While the computation of F1 and F2 is rather simple, F3 necessitates some more steps. The first term's (F1) contribution to the final CCME WQI score has been found to be larger than the contributions of the other two terms.

The water quality index was calculated using three factors as follows: These factors are F1 which is the scope, F2 represents the frequency and F3 which represents the amplitude.

$$CCMEWQI = 100 - \frac{\left[\sqrt{F_1^1+F_2^2+F_3^3}\right]}{1.732} \text{------- Eq 1}$$

F_1 (**Scope**) *represents the percentage of parameters that do not meet their guidelines at least once* during the period under consideration ("failed parameters"), relative to the total number of parameters measured:

$$F_1 = \frac{Number\ of\ failed\ parameters}{Total\ number\ of\ parameters} * 100 \text{ -------Eq 2}$$

*F_2 (***Frequency***) represents the percentage of individual tests that do not meet guidelines ("failed tests"):*

$$F_2 = \frac{Number\ of\ failed\ test}{Total\ number\ of\ test} * 100 \text{ ----------- Eq 3}$$

*F_3 (***Amplitude***) represents the amount by which failed test values do not meet their guidelines.* F3 is calculated in three steps.

i) The number of times by which an individual concentration is greater than (or less than, when the guideline is a minimum) the guideline is termed an "excursion" and is expressed as follows. When the test value must not exceed the guideline:

$$excursion = \frac{Failed\ Test\ valuei}{Objectivej} - 1 \text{ ------- Eq 4}$$

For the cases in which the test value must not fall below the guideline:

$$excursion = \frac{Objectivej}{Failed\ Test\ valuei} - 1 \text{ ------- Eq 5}$$

ii) The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their guidelines and dividing by the total number of tests (both those meeting guidelines and those not meeting guidelines). This parameter, referred to as the normalized sum of excursions, or nse, is calculated as:

$$nse = \frac{\sum_{i=1}^{n} excursion}{\#of\ test} \text{ ------- Eq 6}$$

F3 is the calculated by an asymptotic function that scales the normalized sum of the excursion from guidelines (nse) to yield a range between 0 and 10.

$$F_3 = \frac{\text{nse}}{0.01nse + 0.01} \text{ ------ Eq 7}$$

Once the factors have been obtained, the index itself can be calculated by summing the three factors as if they were vectors and using the Pythagoras theorem. The sum of the squares of each factor is therefore equal to the square of the CCME WQI.

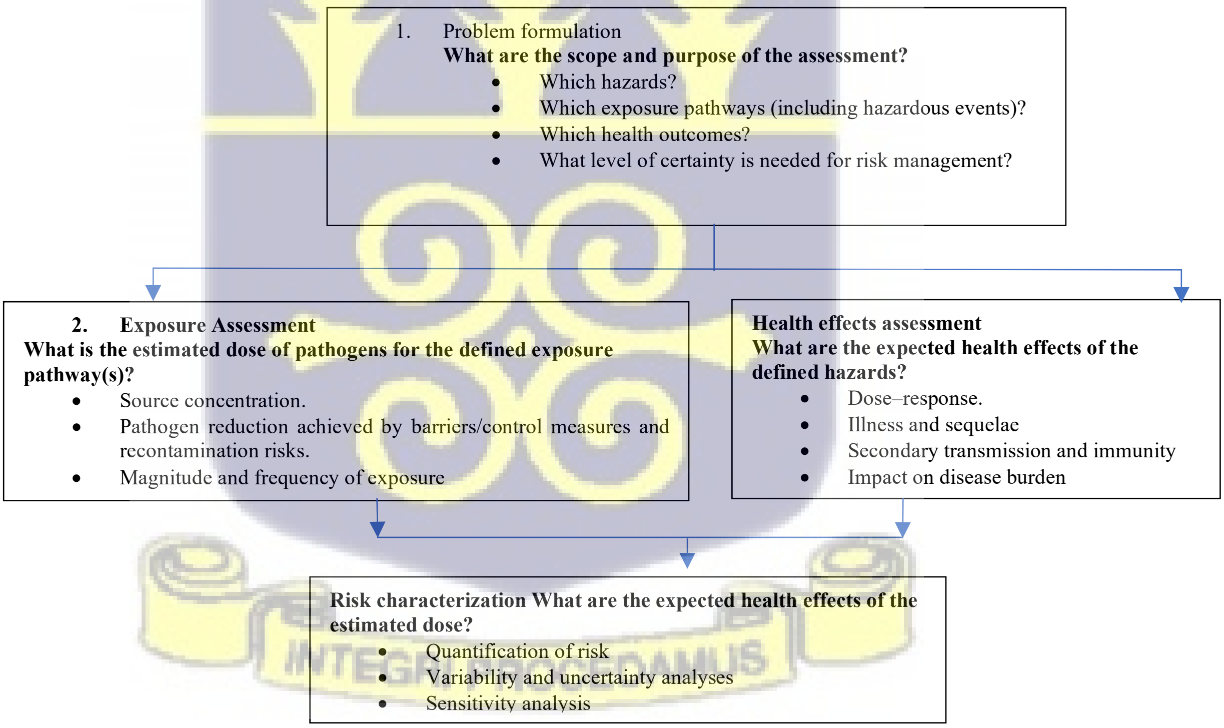
The divisor 1.732 normalizes the resultant values to a range between 0 and 100, where 0 represents the "worst" water quality and 100 represents the "best" water quality (Dao et al., 2020).

Table 4. WQI Designations

Designation	Index value	Description
Excellent	95-100	All measurements are within objectives virtually all the time
Good	80-94	Conditions rarely depart from natural or desirable levels
Fair	65-79	Conditions sometimes depart from natural or desirable levels
Marginal	45-64	Conditions often depart from natural or desirable levels
Poor	0-44	Conditions usually depart from natural or desirable levels

3.20 Human Risk Assessment

3.20.1 Quantitative Microbial Risk Assessment



1. Problem formulation
What are the scope and purpose of the assessment?
- Which hazards?
- Which exposure pathways (including hazardous events)?
- Which health outcomes?
- What level of certainty is needed for risk management?

2. **Exposure Assessment**
What is the estimated dose of pathogens for the defined exposure pathway(s)?
- Source concentration.
- Pathogen reduction achieved by barriers/control measures and recontamination risks.
- Magnitude and frequency of exposure

Health effects assessment
What are the expected health effects of the defined hazards?
- Dose–response.
- Illness and sequelae
- Secondary transmission and immunity
- Impact on disease burden

Risk characterization What are the expected health effects of the estimated dose?
- Quantification of risk
- Variability and uncertainty analyses
- Sensitivity analysis

Figure 7: Diagram for Microbial Risk assessment.

Quantitative microbial risk assessment was used to calculate the risk of infection of the population exposed to the microorganism in the studied water. The calculation was based on contaminates detected in water samples in the present study. Quantitative microbial risk assessment (QMRA) is a mathematical modelling tool used to estimate the risk of infection, risk of mortality and disease burden when the population is exposed to microorganisms in the environment (Haas *et al.,* 2014). This model determines the impact of microorganisms in the environment on the health of the population. Just like other risk assessment tools, the first step is hazard identification. The microorganisms of interest to this study were Total Coliforms, Fecal Enterococci, E. coli, Salmonella spp., Shigella spp. In this study, focus was on E. coli, Salmonella spp., and Shigella spp. This is because the Dose-response for Total Coliform and Fecal Enterococci has not yet been established.

The second step is exposure assessment which involves the measurement of the dose, or the amount of microorganism individuals are exposed to. It is a combination of the number of microorganisms in the environmental medium like water. The measured water quality values from the current study were used for the calculation.

Dose-response is the third step. This step involves selecting and using the right model. Dose-response models have been created for a variety of microorganisms and each model is specific to a microorganism and route of exposure.

Researchers created these models' using data from studies that investigated how many people were infected when exposed to a certain amount of microorganism of interest.

These models have been found to best fit experimental data. For the beta-Poisson model, the probability of infection from a single exposure, P, can be described as follows:

$$P = 1 - (1 + \frac{N}{\beta})^{-\alpha} \text{ ------- Eq 1}$$

where N is the number of organisms ingested per exposure and represent parameters characterizing the host virus interaction (dose–response curve).

$$P = 1 - exp(-r\text{N})\text{-------- Eq 2}$$

Once a dose is calculated and a dose-response model has been selected, the next step is risk characterization, which puts all the information together. The calculated dose is put into the dose-response model, and the answer to the equation tells us how likely a person is to get infected from exposure to this microorganism. The dose response for E. coli is (pathogenic strains) beta-Poisson α= 0.1705 and β = 1.61E06 Salmonella (non-typhoid) Exponential (r) 0.00752 (Gerba et al., 1999), and Shigella beta-Poisson α= 0.21 and β = 42.86 (Haas et al., 1999). Results from the microbial water quality analysis with their corresponding dose-response values were put into the model to determine the risk of infection, risk of mortality and disease burden of residence who drink from these water sources in the Talensi district (Rose et al., 1995; Crockett et al., 1996). Below are the steps and formular used in quantitative microbial risk assessment.

Table 5. Simplified procedure for quantitative microbial risk assessment (adapted from WHO 2004)

Raw water quality, organisms per liter (CR)	Will probably be calculated from concentrations in standard. volumes (e.g., 100 ml) and may not be directly for pathogens
Treatment	Estimated or calculated removal of pathogens
Drinking water quality (CD)	CR - (1-PT)
Consumption of unheated drinking water (V)	Estimated or calculated
Exposure by drinking water, organisms per litre (E)	CD * V

Dose-response	From literature
Risk of infection per day ($P_{inf,\ d}$)	$P_i = 1 - (1 + \frac{N}{\beta})^{-\alpha}$ (Gerba., 1996)
Risk of infection per year ($P_{inf,\ y}$)	$P_{inf,y} = 1 - (1 - P_{inf,d})^{365}$ (Haas et al., 1999)
Risk of diarrhoeal disease given infection ($P_{ill|inf}$)	From literature
Risk of diarrheal disease (P_{ill})	$P_{ill} = P_{inf,y} * P_{ill|inf}$
Maximum disease burden (mdb)	Calculated from available data and from data reported in literature
Susceptible fraction (fs)	From literature
Disease burden (DB)	P_{ill} * mdb * f_s
Risk of mortality (R_m)	From literature
Risk of mortality	$Risk\ of\ mortality = P_{inf,d} * P_{ill/inf} * R_m$ (Gerba., 1996)

3.20.2 Chemical Risk Assessment

To determine the likelihood that people who may be exposed to chemicals in contaminated water may experience negative health impacts, health risk assessment of water contaminants is beneficial. Based on contaminants found in water samples from the current investigation, health risks associated with water pollution were estimated. Health risk indices by ingestion were evaluated using empirical models put forward by USEPA (1998). This was used to estimate the non-carcinogenic effects of contaminants in this study. The average daily dose of single element can be calculated using the following equation:

$$CDI = \frac{Cw*IR*EF*ED}{BW*AT} \text{ -------- Eq 1}$$

Where CDI is the exposure dose through intake of water (mg/kg/day): Cw is the concentration of a particular contaminant in water (mg/L): IR, ingestion rate in this study 2L day^{-1} was used (USEPA, 2001). EF, exposure frequency was 365 days, and the ED, exposure duration in this study was 30 years for adults (USEPA, 2001). BW: average body weight; in this study, 70 kg for adults (USEPA, 2002). AT: averaging time; for non-carcinogens, ED×365 days.

Before a risk is characterized, the hazard quotient (HQ) of the individual pollutants is computed using the following equation (Wongsasuluk *et al,* 2011):

$$\text{Hazard Quotient} = \frac{\text{CDI}}{RfD} \text{--------}Eq\ 2$$

Where RfD represents the refence dose of a specific contaminant. An *RfD* is a daily oral intake rate that is estimated to pose no appreciable risk of adverse health effects, even to sensitive populations, over a 70-year lifetime. Similarly, an *RfC* is an estimated daily concentration of a chemical in water, the exposure to which over a specific exposure duration poses no appreciable risk of adverse health effects, even to sensitive populations (Gaylor & Kodell, 2002). The oral reference dose of Nitrate is 1.6mg/kg/d, Fluoride is 0.4 mg/kg/d, Mercury is 0.003mg/kg/d and Arsenic is 0.0003mg/kg/d. These were obtained from the data base of IRIS (Integrated Risk Information System, USEPA 2012. HQ of less than or equal to 1 is considered health-protective (U.S. EPA 2000e).

The total chronic hazard attributable to exposure to all analyzed contaminants through a single exposure pathway is known as a hazard index (*HI*) or the sum of individual acute or chronic hazard quotients for each substance affecting a particular endpoint. The *HI* is calculated as follows:

$$\text{HI} = \text{HQ Fluoride} + \text{HQMercury} + \text{HQArsenic} \text{ ------- Eq 3}$$

$$\text{HI} = \text{HQNitrate} + \text{HQArsenic}\text{--------Eq 4}$$

Hazard Indices were calculated for multiple substance acting by similar mechanism or having the same target organ. As, Hg and F^- all have the kidney as their target organ and As and NO_3^- have the liver as their target organ.

3.20.3 Cancer Risks

To assess the carcinogenic risk, a comprehensive analysis was performed using the United States Environmental Protection Agency's (USEPA) Integrated Risk Information System (IRIS) methodology (LaGrega et al., 2010). This involved evaluating the concentration of arsenic in the water samples, the estimated daily intake of arsenic by the local population, and the potential risks associated with long-term exposure.

$$CDI = \frac{\mathrm{Cw*IR*EF*ED}}{BW*AT}\text{----------Eq1}$$

$$Risk = \mathrm{(CDI)(Potency\ Factor)}\text{----------Eq2}$$

CW: site-specific measured or modeled value IR: 2 L/day (adult, 90th percentile); EF: pathway-specific value (dependent on the frequency of exposure-related activities) ED: 70 years (lifetime; by convention); 30 years national upper-bound time. BW: 70 kg (adult, average); Age-specific values AT: pathway-specific period of exposure for noncarcinogenic effects (i.e., ED 365 days/year), and 70-year lifetime for carcinogenic effects (i.e., 70 years 365 days/year), averaging time.

Potency factor is the slope of the dose–response curve at low doses. At low doses, the slope of the dose– response curve produced by the multistage model is called the potency factor. It is the risk produced by a lifetime average dose of 1 mg kg^{-1} day^{-1} (USEPA, 1990).

Thus, for noncarcinogenic chemical responses, the assumption is that some threshold exists below which there is no toxic response; that is, no adverse effects will occur below some very low dose for example, one in a million. Carcinogens, however, are considered no threshold—that is, the conservative assumption is that exposure to any amount of carcinogen creates some likelihood of cancer. This means that the only “safe” amount of carcinogen is zero, so the dose–response plot is required to go through the origin (0).

3.21 Ethical Considerations

3.21.1 Ethical Clearance

Ethical approval for the study protocol was obtained from Nouguchi Memorial Institute for Medical Research and Ethics Committee of the Faculty of Environmental and Life Sciences, University of Southampton, UK.

3.21.2 Consent for Participation

Letter requesting for permission and collaboration were presented to the Talensi District Office and Chiefs of the selected communities. Also, consent was sought prior to interviews from Assembly men and unit committee leaders to enter the community, and from study participants accordingly. Participation was on voluntary basis, and participants had a full right to withdraw from the interview process at any time of the data collection. COVID -19 Protocols were duly followed to avoid the risk of contracting the disease.

3.21.3 Information Confidentiality Assurance Mechanisms

Data collected for the study was kept confidential and used solely for the purpose indicated by the study. Participants were not coerced into taking part in the study. Questionnaires were kept in locked metallic cabinets at the offices. The data entered into the statistical software were kept using password locks for data files.

3.22 Dissemination plan

The findings of this study are planned to be disseminated to different stakeholders, accordingly, using the following mechanisms. The finding will be presented at international research conferences. In addition, efforts will be made to publish the findings in different open access peer review journals. Furthermore, policy brief will be prepared to communicate with policy makers at regional, national, and international levels accordingly. In addition, the findings of this study will be disseminated to the District Office and public, particularly the study communities.

3.33 Sample pictures of project fieldwork

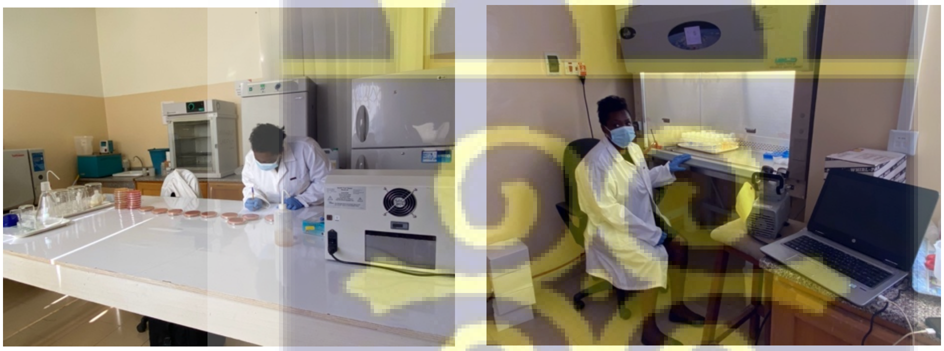
Photos were taken during field work in both survey season. A verbal consent was obtained from group and individuals before taking.

Sampling from stream

Sampling from stream and household

Flaming and sampling from borehole

FDG and sanitary inspection appraisal



Laboratory analysis

CHAPTER FOUR

RESULTS

4.0 Introduction

All the results obtained from the study are reported in this chapter. The results are divided into 5 sections. The descriptive socio-demographic characteristics as well as access to improved drinking water sources are presented in the first section. Water quality parameters and sanitary risk assessment are elaborated. In addition, the chapter presents the health risk assessment as a result of exposure to water in the communities. Lastly the geospatial distribution of water contaminants with population at risk and land Use/land Cover change is reported. The chapter concludes on the qualitative component on access to improved water sources.

To identify factors associated with households' access to improved water sources in the Talensi District during rainy and dry season.

4.1 Sociodemographic characteristics of quantitative study participants

The mean ± SD age of the household heads was 46.2 ± 16.5 during the rainy season and 44 ± 10.2 during the dry season. A total of 152 males (63.33%) and 88 (36.67%) participated in the study during the rainy season and 162 males (67.50% and 78 (32.50%) females participated in the dry season (Table 6). The decline in the number of female house heads during the dry season was because some of them travel to the southern part to work when the rains stop. The majority of the respondents were Traditionalist 115(47%), 107 (44.6%) were Christians, 17

(7.08%) were Moslems with 0.42% representing other type of religion. About 67% of the household heads were married, 8% were single and 23% were Widowed.

4.1.2 Background characteristics of the qualitative study participants

A total of fifty (50) participants were involved in this study. The participants for the Key Informant Interview included representatives from the district offices and community leaders (n=10). The total number that participated in the Focus Group Discussion (FGDs) was (n=40). The mean ± SD age of the of key informants was 38 ± 9.7. The mean ± SD age for community members (FGDs) was 44.3 ± 9.2. Most of the key informants were males (n=9) with only one woman making (n=1) while community FGDs comprised 19 females and 21 males with the highest educational level of education being Tertiary level (Supplementary Table 1).

4.2 Households access to improved water sources

Objective one of this study examines the factors that influence households' access to improved water sources. There was a decline in the proportion of households' access to improved water sources during the dry season (z=3.244, p= 0.0012). The main sources of water during the dry season were boreholes (60.82%). Other sources of water during the dry season included hand dug well (10.83%), protected well (2.0%), river/stream (0.45%), tanker supply (11.70%), and unprotected wells (14.20%). The main sources of water during the rainy season were boreholes (55.09%), harvested rainwater (30.83%), protected wells (2.83%), tanker supply (2.08%), and unprotected wells (9.17%). Nearly all the participants (90.83%) had access to improved water during the rainy season and 9.17% used unimproved drinking water services. However, 81.67% used improved water service during the dry season while (18.33%) used unimproved drinking water services. During the dry season only (2.08%) of the population used improved drinking water that is accessible on their premises. Furthermore (40.4%) used basic drinking water services which means they had access to improved sources within a 30-minute round trip including queuing time. Also, (39.13%) had limited access to drinking water as they had to travel more than 30 minutes for a roundtrip including queuing. Meanwhile, (18.38%) of the population had to rely on water from unimproved sources.

Data from the rainy season indicated that 30% of the total respondents used improved drinking water that was accessible on their premises, whilst (38.8%) used basic drinking water services that had access to improved source, provided collection time was not more than 30 minutes for a round-trip including queuing. Further (22.07%) used limited services that is drinking water from an improved source for which collection time exceeds 30 minutes for a roundtrip including queuing and 9.17% used water from unimproved source.

There was a significant difference in the median time spent to get water during the dry and rainy seasons. During the dry season, the time spent fetching water was 18.25 (25) minutes, while 10.6 (15) minutes was spent during the rainy season ($p = 0.0465$). From the study, about 81.5 % of the households' store water in covered containers while the remaining 18.15 % of the household's stored water in uncovered containers leaving their water prone to contamination. About (99.19%) of the households never used any form of water treatment and 0.81% used naphthalene balls in treating their water.

Findings from the qualitative study revealed that some community members have access to water from streams or rivers nearby and rainwater (during the rainy seasons) whereas others access their water from nearby communities. For instance, some participants stated that:

> *I always get my water from a river there is a river 10 minutes' walk away from here when it stops raining. I depend on rainwater when the rain starts* ***(R1, Male, Community1, FGD)***
>
> *We always get our water from a different town. For instance, they have to bring us water from Bolga to us in a tanker.* ***(R4, Male, Community1, FGD)***

> *For the mining communities some of them get water from the stream.* ***(KII, Male, Office 2)***

Other participants however noted that they do not have access to any source of water.

> *I don't get water at all (**R5, Female, Community1, FGD)***

> *I don't just have water at all (**R7, Male, Community1, FGD)***

For the non-mining communities, most of the participants stated that they have access mainly to mechanized sources of water in addition to the stream:

> *Most of the communities have boreholes. Even this enclave alone has four boreholes* ***(KII, Male, Community 2)***

> *We normally get our water from the borehole here. (**R7, Female, Community 2, FGD)***

> *We get our water from the stream. (**R5, Male, Community 2, FGD)***

Participants further revealed that it was easy to have access to water during the rainy season compared to the dry season in both mining and non-mining communities:

> *It's always in the rainy season that we get the water but in the dry season we get water from the stream to bath (**R8, Female, Community 1, FGD)***

> *In the dry season, the stream dries up, so we dig in the stream way and wait for water to spring up and then we fetch. This is time consuming because you must wait for the sand to settle before we can fetch. (**R3, Female, Community 1FDG**).*

> *When it gets to the rainy season, access to water is not much of a problem because there are some dams around. They may use that for washing and other domestic purposes but not for drinking. But in the dry season, they rely on the (**KII, Male, Office 2)***

> *The year we get heavy or more rain, we get water throughout the season. Any year we get less water, by January or February, all those four boreholes dry up. (**KII, Male, Office 4)***

Table 6: Distribution of the study samples for both seasons unweighted.

Variables	Rainy Season N=240 n (%)	Dry Season N=240 n (%)	Z-Value	P-Value
Sex			2.673	0.0075**
Male	152 (63.33)	162 (67.50)		

Female	88 (36.67)	78 (32.50)		
Access to water			3.244	0.0012**
Improved water	218 (90.83)	196 (81.67)		
Unimproved water	22 (9.17)	44 (18.33)		
Household size			0.313	0.7544
1-5	122 (50.83)	120 (50.00)		
6-10	101 (42.08)	101 (42.08)		
Above 10	17 (7.08)	19 (7.92)		
Educational level			1.459	0.1445
None	146 (60.83)	137(57.08)		
Primary	34 (14.17)	42 (17.50)		
Middle/JHS	34 (14.17)	33 (13.75)		
Secondary or above	26 (10.83)	28 (11.67)		
Wealth tercile			0.111	0.9116
Poor	78 (32.50)	78 (32.50)		
Middle	85 (35.42)	85 (35.42)		
Rich	77 (32.08)	77 (32.08)		
Place of residence			-	-
Mining	120 (50)	120 (50)		
Non- mining	120 (50)	120 (50)		
Time spent				
On premises	76 (31.67)	6 (2.50)	-6.733	0.0000**
1-30m	99 (41.25)	109 (45.42)		
30-1h	29 (12.08)	102 (42.50)		
Above 1h	36 (15.00)	23 (9.58)		
Sanitation facility			-	-
Improved	68 (28.45)	68 (28.45)		
Unimproved	171 (71.55)	171 (71.55)		
Temperature°C			13.525	0.0000**
25.29-25.39	60 (25.00)	-		
25.40-25.88	53 (22.08)	-		
25.89-25.93	127 (52.92)	-		
26.78-27.78	-	122 (58.83)		
27.79-27.98	-	58 (24.17)		
27.99-29.05	-	60 (25.00)		
Precipitation mm			-13.691	0.0000**
0	-	240		
3.95	62 (25.83)	-		
5.71	60 (25.00)	-		
6.86	118 (49.17)	-		

p-value notations: $p<0.05$*; $p<0.01$**

4.3 Factors associated with households' access to improved water sources.

The independent association of background characteristics with access to improved source in both survey seasons is presented in Table 8. Some of the household background characteristics were significantly associated with the outcome variable in both survey season.

Wealth index was significantly associated with household access to water in both survey season, while the proportion with access to improved water source was comparatively lower among household in the poor wealth tercile (29.36%). Household heads whose highest educational level was Secondary school or higher had the highest level of access to improved water sources (98.18%). Place of residence was significantly associated with improved water access. There are stark differences between non-mining and mining areas. In non-mining areas, 54.59% have improved water compared to only 45.41% in mining areas ($X^2 = 10.6006$, $p = 0.001$ for rainy; $X^2 = 14.8593$, $p = 0.000$ for dry). Environmental factors like temperature and rainfall were associated with households' access to improved water sources. Higher temperatures correlate with lower access to improved water. The association is significant in both seasons ($X^2 = 11.5625$, $p = 0.003$ for rainy; $X^2 = 20.6971$, $p = 0.000$ for dry).

Some participants expressed that, the water sources in the mining communities are mostly affected due to the activities of the mining companies:

*"Because these areas, they have been mining for a long time, it has affected the quantity and quality of the underground water". **(KII, Male, Office 2)***

*Because the mining activities have gone deeper than the height of the pipes of the borehole, all the boreholes that were drilled at the mining sites does not yield any water because they are hanging. **(KII, Male, Office 3)***

Given the results of the multivariable logistic regressions for access to improved water sources in both survey seasons, different factors were strongly associated with the access to improved water sources. During the rainy season, environmental factors like temperature and rainfall were associated with access to improved water sources. Household factors like the wealth index were also significantly associated with access to improved water sources.

The adjusted and unadjusted logistics regression analyses are summarized in Table 8 and 9. Compared to female-headed households, male-headed households were less likely to have access to improved sources of drinking water during the rainy season compared to female headed households (AOR: 0.3; 95% CI: 0.1-0.8 *p*= 0.0115). Also, in the dry season male headed households had lower odds of accessing improved water (AOR: 0.1; 95% CI: 0.01-0.5 *p*= 0.0005). In the rainy season, the variable sex of household head significantly affects the odds of improved water access. Being that male-headed household decreases the odds of improved water access compared to being in a female-headed households.

Households head level of education does not significantly improve the model's ability to predict improved water access during the rainy season primary school (AOR: 2.2 95% CI 1.1-5.5 *p* = 0.058), middle school (AOR: 2.9 9 5% CI 0.4-6.3 *p* =0.569) and secondary school and above 3.6 9 5% CI 0.1-6.9 *p*= 0.0853). Compared to non-mining area households, mining areas were less likely to have improved water access (AOR: 0.06; 95% CI: 0.01-0.4; p=0.011) in the rainy season.

Compared to the rainy season, during temperature was a significant predator improved water access during the rainy season. Temperatures of 25.40-25.88°C are less likely to have improved water access compared to the baseline (OR: 0.2; 95% CI: 0.03-0.7; p=0.019), during temperatures of 25.89-25.93°C (OR: 0.3; 95% CI: 0.1-0.7; p=0.007). During the dry season, temperatures of 27.79-27.98°C (OR: 0.2; 95% CI: 0.03-07; p = 0.002) residents had lower odds of access to improved water sources and also between 27.29.05°C and 29.05°C households were 82.9% less likely to have access to improved water during the dry season.

The qualitative study participants recounted some challenges that affect their access to improved water sources, these challenges include mining and dry season. The effect of mining activities in communities has emerged as one of the major challenges to household access to an improved water source. Many participants expressed that their natural sources of water have been adversely affected by the mining activities and this is expressed in the quotes below:

> *We have gold miners here who have drained the water, and the water table has gone down so even if they sink a borehole, you will not get water* ***(FGD R2, Male, Community 1,).***
>
> *In the communities where they mine, when we drill boreholes, we are not able to get water. Mining is a challenge* ***(KII, Male District assembly).***
>
> *They do a lot of water pumping from mining tunnels they dig. As they pump water every day, it reduces the water table. They also use some toxic chemicals like mercury which are very harmful to their health.* ***(KII, Male District assembly).***
>
> *The major challenge is the road. Anytime it rains, those who supply us with water from other towns find it challenging to bring the water* ***(FGD R7, Female, Community 1).***
>
> *The water they bring is very expensive, so we find it difficult to buy sometimes* ***(FGD R3, Female, Community 1).***
>
> *We walk a long distance to fetch water* ***(FGD R5, Female, Community 2).***

However, for the non-mining communities, barriers to improved water sources were mainly due to sanitation challenges and institutional challenges such as the availability of electricity as most of the mechanized boreholes operate using electrical power.

> *The mechanized boreholes use electricity so during light outs pumping water becomes a problem. Some of the boreholes also break down sometimes* ***(KII, Male, Office 3).***
>
> *It's just the open defecation that pollutes our water* ***(FGD R2, Female, Community 2).***

Table 7: Distribution of household/environmental characteristics by access to improved drinking water sources in each survey season.

Variables	Water sources rainy season % Improved (95% CI)	Unimproved (95% CI)	X^2	P-value	Water sources dry season % Improved (95% CI)	Unimproved (95% CI)	X^2	P- value
Sex			5.2446	0.022*			9.6018	0.002**
Male	65.60 [36.09,78.03]	40.91 [17.88,68.44]			71.94 [69.88, 85.47]	47.73 [24.45, 54.74]		
Female	34.40 [23.23,44.93]	59.09 [30.41,72.9]			28.06 [14.53, 47.56]	52.27 [48.22,67.95]		
Age			10.2784	0.006**			9.8683	0.007**
15 – 34	26.61 [16.15,38.26]	59.09 [25.78,70.93]			33.67 [22.65, 44.29]	59.09 [48.22,67.95]		
35 – 54	42.66 [32.84,56.64]	27.27 [8.225,41.42]			34.69 [23.62,47.56]	22.73 [12.85, 33.84]		
55/Above	30.73 [23.23,44.93]	13.64 [7.355,22.93]			31.63 [21.12, 43.73]	18.18 [15.2, 31.73]		
Household size							7.8770	0.019**
1-5	49.08 [36.92,60.02]	68.18 [49.82,73.16]	3.7281	0.155	53.57 [41.95, 66.59]	34.09 [22.65, 44.29]		
6-10	44.04 [20.52,39]	22.73 [12.60,32.07]			40.31 [29.15, 53.25]	50.00 [48.22, 67.95]		
10/Above	6.88 [2.443,11.25]	9.09 [3.868,19.07]			6.12 [2.248, 13.24]	15.91 [7.417, 20.72]		
Educational level			8.4033	0.038*			7.9143	0.048*
None	61.01 [49.82,73.16]	59.09 [17.88,68.44]			54.08 [45.57,66.71]	70.45 [49.25, 81.23]		
Primary	12.39 [6.336,20]	31.82 [27.02,49.7]			16.84 [7.97,34.31]	20.45 [15.19, 48.28]		
Middle/JHS	14.68 [8.974,24.4]	14.68 [10.24,27.9]			15.31 [9.20 ,25.08]	6.82 [1.602, 32.1]		
Secondary/above	11.93 [6.259,19.25]	11.93 [6.704,18.83]			13.78 [8.82,23.14]	2.27 [1.679,10.52]		
Wealth tercile			11.6693	0.003**			8.4196	0.015*
Poor	29.36 [20.52,39]	63.64 [48.16,71.92]			30.61 [20.23,43.63]	40.91 [18.22-68.9]		
Middle	36.24 [29.6,52.83]	27.27 [19.22,39.08]			33.16 [22.65,44.29]	45.45 [23.91,61.08]		
Richer	34.40 [11.71,48.76]	9.09 [5.67,12.22]			36.22 [26.8,50.36]	13.64 [8.974,24.4]		
Place of residence			10.6006	0.001**			14.8593	0.000**
Non-mining	54.59 [45.57,66.71]	18.18 [8.39,24.17]			57.14 [35.2,68.27]	25.00 [15.26,35.42]		
Mining	45.41 [26.28,57]	81.82 [45.99,96.58]			42.86 [35.45,58.13]	75.00 [67.88,87.8]		
Cost of water			3.9835	0.046*			4.3105	0.038*
Yes	6.42 [2.521,15.54]	18.18 [9.205,25.08]			17.86 [8.377,33.73]	31.82 [13.76,58.58]		

No	93.58 [89.48,97.1]	81.82 [70.07,92.88]			82.14 [53.51-96.35]	68.18 [23.91,71.08]		
Temperature°C			11.5625	0.003**			20.6971	0.000**
25.29-25.39	22.02 [14.15,34.54]	54.55 [47.76,68.72]						
25.40-25.88	23.39 [16.16,36.56]	9.09 [5.988,17.97]						
25.89-25.93	54.59 [17.88,68.44]	36.36 [27.02,49.7]						
26.78-27.78					43.88 [26.28,67]	81.82 [67.37-89.6]		
27.79-27.98					27.55 [8.225,51.42]	9.09 [5.546,13.41]		
27.99-29.05					28.57 [20.52,39]	9.09 [5.546,13.41]		
Precipitation mm			11.3673	0.003**			-	-
0					100.00	100.00		
3.95	26.61 [20.52,39]	18.18 [8.39,24.17]						
5.71	22.02 [15.77,40.22]	54.55 [27.32,79.69]						
6.86	51.38 [20.31,72.68]	27.27 [18.5,43.06]						
Time spent			11.3086	0.010*			10.0097	0.018*
On Premises	33.03 [24.61,46.43]	18.18 [10.24,27.9]			2.55 [0.54,9.78]	2.27 [0.73,10.72]		
1-30m	42.66 [25.73,54.84]	27.27 [19.22,38.08]			49.49 [35.66,58.91]	27.27 [17.88,37.8]		
30-1h	10.09 [2.831,20.56]	31.82 [25.93,48.62]			37.76 [16.87,57.77]	63.64 [18.83,71.28]		
Above 1h	14.22 [9.36,24.37]	22.73 [14.15,34.54]			10.20 [2.014,31.56]	6.82 [2.34-15.77]		

p-value notations: $p<0.05$*; $p<0.01$**

Table 8. Comparison of unadjusted and adjusted odds ratio on factors associated with access to improved water source in Talensi during the rainy seasons.

	Crude OR (95% CI)	*p*-value	Adjusted OR (95% CI)	*p*-value
Sex		0.0250*		0.0115*
Female	1		1	
Male	0.3 [0.1-0.8]]		0.2 [0.03-0.6]	
Age		0.0031**		0.0540
15 - 35	1		1	
35 - 54	0.4 [0.2-0.7]		0.3 [0.06-1.2]	
Above 55	0.5 [0.2-1.6]		0.1 [0.02-0.8]	
Household size		0.1363		0.5212
1-5	1		1	
6-10	0.3 [0.1-1.1]		0.4 [0.1-1.8]	
Above 10	0.9 [0.2-4.5]		1.0 [0.2-6.7]	
Education level		0.1180		0.0953
None	1		1	
Primary	1.7 [0.9-3.2]		2.2 [1.1-5.5]	
Middle/JSS	0.6 [0.1-2.9]		2.9 [0.4-6.3]	
Secondary or above	2.3[0.1-5.1]		3.6 [0.1-6.9]	
Wealth tercile		0.0029**		0.0025
Poor	1		1	
Middle	0.3 [0.1-0.9]		0.1 [0.04-0.7]	
Rich	0.1 [0.02-0.5]		0.1 [0.01-0.3]	
Place of residence		0.1383		0.0119*
Non-mining	1		1	
Mining	0.36 [0.1-1.3]		0.06 [0.01-0.4]	
Cost of water		0.0808		0.1424
No	1		1	
Yes	3.2 [0.9-10.0]		0.2 [0.03-1.7]	
Temperature°c				0.2962
25.29-25.39	1	0.0059**	1	
25.40-25.88	0.2 [0.03-0.7]		0.2 [0.02-1.9]	
25.89-25.93	0.3 [0.1-0.7]		0.9 [0.05-6.0]	
Precipitation Mm		0.0070**		0.2744
3.95	1		1	
5.71	3.6 [1.0-5.9]		0.4[0.1-1.8]	
6.86	0.8 [0.2-2.8]		0.2 [0.1-3.0]	

p-value notations: $p<0.05$*; $p<0.01$**

Table 9. comparison of unadjusted and adjusted odds ratio on factors associated with access to improved water source in Talensi during the dry seasons.

	Crude OR (95% CI)	*p*-value	Adjusted OR (95% CI)	*p*-value
Sex		0.0025**		0.0005**
Female	1		1	
Male	0.4 [0.2 -0.7]		0.1 [0.01-0.5]	
Age		0.0081**		0.0045*
15 - 35	1		1	
35 - 54	0.4 [0.2-.08]		0.2 [0.07-0.7]	
Above 55	0.3 [0.1-0.7]		0.1 [0.03-0.4]	
Household size		0.0251*		0.0647
1-5	1		1	
6-10	1.9[0.9-3.9]		2.7 [1.0 -7.3]	
10/ above	4 [1.3-11.2]		3 [0.8 – 9.8]	
Education level		0.0205*		0.0469*
None	1		1	
Primary	0.9 [0.4-2.2]		0.5 [0.1- 1.8]	
Middle/JSS	0.3 [0.09-1.2]		1.3[0.1-2.5]	
Secondary or above	0.1 [0.01-1.0]		2.0 [0.2-4.3]	
Wealth tercile		0.0086**		0.0079*
Poor	1		1	
Middle	1.0 [0.5-2.1]		1.0 [0.2-2.3]	
Rich	2.0 [0.1-3.7]		2.0 [0.03-0.43]	
Place of residence		0.0001**		0.0134*
Non-mining	1		1	
Mining	0.4 [0.1-2.3]		0.9 [0.2-3.1]	
Cost of water		0.0465*		0.3044
No	1		1	
Yes	2.1 [1.0-4.4]		1.6 [0.6 -4.5]	
Temperature°C		0.0000**		0.0201*
26.78-27.78	1		1	
27.79-27.98	0.2 [0.03-07]		0.4 [0.04-1.4]	
27.99-29.05	0.3 [0.1-0.7]		0.1 [0.01- 0.5]	

p-value notations: $p<0.05$*; $p<0.01$**

To assess a seasonal variability of water quality and to determine the water quality index of water in Talensi District.

4.5 Water quality Parameters

Table 12. Sampling analysis techniques and detection limits

Parameters	Method	Detection limit	WHO guideline
pH	APHA 4500 H+B	0.00	6.5–8.5
Temperature	APHA 2510B		22-29
Electrical conductivity	APHA 2520B	1 µS/cm	400 µS/cm
Total Dissolved Solids			1000 mg/L
Excellent			Less 300mg/l
Good			Between 300-600 mg/L
Fair			Between 600-900 mg/L
Poor			Between 900-1200 mg/L
Unacceptable			Above 1200 mg/L
Fluoride	APHA 5210 B	0.02 mg/L	1.5 mg/L
Nitrate	APHA 4500 D	0.1 mg/L	11.0 mg/L
Arsenic	EPA 7010/ EPA 7000		0.01 mg/L
Lead		0.001 mg/l	0.01 mg/L
Mercury		0.0001 mg/l	0.006 mg/L
Total coliform			0 count/100ml
Fecal Enterococci	APHA 9230 A		0 count/100ml
E. coli	APHA 9222 H		0 count/100ml
Shigella spp.	APHA 9260 E		0 count/100ml
Salmonella spp.	APHA 9260 B		0 count/100ml

Table 13. Median and Interquartile range of water quality parameters

	RAINY SEASON	DRY SEASON		
Parameter	Median (IQR)	Median (IQR)	Wilcoxon signed-Rank Test	P-value
Physico chemical				
pH	7.6 (0.9)	7.9 (0.4)	-2.220	0.0264*
Temperature	25.8 (0.5)	30.9 (0.8)	-9.223	0.0000***
Electrical conductivity	400.2 (226.5)	423.9 (145.7)	-1.955	0.0506
Total Dissolved Solids	197.2 (110.7)	209.2 (71.1)	-2.133	0.0329*
Chemical				
Fluoride	0.6 (0.8)	0.2 (0.4)	5.078	0.0000**
Nitrate	2.5 (3.3)	3.0 (7.8)	-2.679	0.0074*
Arsenic	0.002 (0.002)	0.003 (0.003)	0.826	0.4087*
Lead	bdl	bdl	bdl	bdl
Mercury	0.0002 (0.0005)	0.0006 (0.0004)	-3.443	0.0006**
Microbial				
Total coliform	134.5 (116)	75.5 (150)	3.379	0.0007**
Fecal Enterococci	40.5 (102)	0 (31)	4.270	0.0000**
E. coli	45 (84)	0 (10)	5.410	0.0000**
Shigella spp.	0 (7)	0 (0)	3.726	0.0002**
Salmonella spp.	0 (9)	0 (0)	3.602	0.0003**

p-value notations: $p<0.05$*; $p<0.01$**

4.5.1 pH, temperature, Electrical Conductivity, Total Dissolved Solids.

The pH recorded at the study sites during the rainy season ranged between 6.4 to 8.5 with a median value of 7.5 (0.9) (Table 13). The pH of water samples during the dry season varied from (6.8-8.5). All samples tested during the dry season were in accordance with the WHO standards. However, water from the rain harvest recorded pH levels (6.44) that were below the acceptable limits of the WHO during the rainy season.

The temperature range of water samples collected during the rainy season was within the WHO guidelines of (22-29°c). In contrast, water temperature generally increased throughout the dry season. The temperature of the samples ranged from (30.1 to 31.7°c) (Supplementary Table 2a). All the samples analyzed during the dry season were above the WHO standards.

Electrical Conductivities of the sampled sources during the rainy season varied from 5.9 to 1026 µS/cm with a median value of 400.2 (226.5). About 50% of the water samples had higher conductivity level above the WHO standards of 400 µS/cm (WHO, 2011). Conductivity level in water samples during the dry season fluctuated from 193.1 to 1053.0 µS/cm, with a median level of 481.08 (145.7) µS/cm. During the dry season 70% of the total samples had conductivity levels above the WHO guideline set for drinking water.

The TDS values ranged between 2.9 and 502 mg/L, with a median level of 197.2 (110.7) mg/L. About 18% of the samples had lower levels of TDS compared to WHO standards, while 76% of the samples were within the excellent limit set by the WHO guidelines. Furthermore 18% of the samples had TDS concentration below 50mg/L which is also classified as unacceptable because it is flat. Six percent (6%) were within the good range. TDS levels in samples collected during the dry season ranged from 94.3 to 518.6 mg/L and a median range of 209.2 (71.1) mg/L. Overall samples were all in the acceptable level of WHO standards, with 82% falling within the excellent region and 18% in the good region. During the rainy season, boreholes and water from reservoirs recorded the highest level of TDS at 236.9 mg/L and 193 mg/L respectively. The streams recorded the lowest TDS during the rainy season (34.1mg/l). TDS value was higher during the dry season than the rainy season.

4.5.2 Nitrate, fluoride, lead, Mercury, Arsenic.

In the samples collected during the rainy season, Nitrate concentration in water samples varied from 0.17 to 28 mg/L (Supplementary Table 2a) with a median value of 2.5 (3.3) mg/L. Nitrate concentration above 3 mg/L is considered because of human activities. About 12% of the samples were above the WHO guideline of 10 mg/L (WHO 2011), with the remaining 88% below the guidelines set by WHO. Nitrate in dry season samples ranged from 0.89 to 79 mg/L with a median value of 3 (7.8) mg/l. Furthermore 78% of the samples were below the WHO standard whiles 22% of the samples were above the WHO guideline value. Water from the reservoirs had the highest levels of NO_3^- (7.75 mg/L) during the dry season.

Fluoride concentrations ranged from 0.17 to 5.5 mg/L with a median value of 0.6 (0.8) mg/L. Approximately 22% of the samples had values exceeding the permissible limits of 1.5 mg/L set by WHO. Fluoride varied from 0.05 to 3.8 mg/L through the dry season. The median fluoride levels were 0.2 (0.4) mg/L, 18% of the samples were above the WHO standards. The highest level of Fluoride was detected in Shia in both seasons (5.50 mg/L) was detected in the rainy season and (3.80 mg/L) was detected during the dry season.

Levels of Lead were not detected in any of the samples during both seasons.

Arsenic levels detected in the current study varied from 0 to 0.049 mg/L with a median of 0.003 (0.003) mg/L during the dry season. The levels fluctuated from 0 to 0.031 mg/L with a median of 0.002 (0.002) mg/L in the rainy season. During the rainy season 84% of the samples had As levels below the WHO guideline, 14% were below detection limit and 2% were above the WHO guideline. About 34% of the samples collected in the dry season was below the WHO guideline, 64% were below detection limit while only 2% was above the WHO guideline value of 0.01mg/L The highest As level was detected in a borehole in Gbane-Obuasi a mining community.

Mercury varied from 0 to 0.0027mg/L with a median of 0.003 (0.0007) mg/L during the rainy season. About 44% of the samples were below WHO standards and the remaining samples were below the detection limit. During the dry season, Hg ranged from 0 to 0.0014mg/L with a median of 0.0006 (0.0004) mg/L. Furthermore 82% of the samples had Hg levels below the WHO guideline value of 0.006mg/l while 18% had levels below the detection limits.

4.5.3 Total Coliform, Fecal Enterococci, E. coli, Salmonella spp., and Shigella spp.,

Total coliforms (TC) count in the water samples from the present study fluctuated between 0 to 480 CFU/100ml. The median value of TC from the study area was 134.5 (116) CFU/100ml. About 88% of the samples had total coliforms above the WHO standards. Water samples collected during the dry season had a minimum level of 0 CFU/100ml and a maximum value of 296 CFU/100ml with a median of 75.5 (150) CFU/100ml. Furthermore 76% of the samples were above the WHO standards while 24% of the samples did not have TC bacteria in them.

Fecal Enterococci counts in the water sources investigated were found to be between 0 and 348 CFU/100ml with an average count of 40.5 (102) CFU/100ml. During the rainy season, 66% of the samples had counts of Fecal Enterococci above the WHO standards. Analysis conducted during the dry season revealed that Fecal Enterococci ranged from 0 to 122 CFU/100ml with a median of 0 (31) CFU/100ml. The organism was detected in 36% of the samples during the dry season.

Total *E. coli* counts in investigated water samples during the rainy season were found to be between 0 and 210 CFU/100ml with a median of 45 (84) CFU/100ml. E. coli count was detected in 82% of the samples, whereas during the dry season, *E. coli* count varied between 0 to 106 CFU/100ml with a median count of 0 (10) CFU/100ml. About 36% of the samples had count levels above the WHO standards.

During the rainy season, Shigella counts fluctuated from 0 CFU/100ml to 132 CFU/100ml. It had a median count of 0 (7) CFU/100ml. Shigella spp., was detected in 28% of the samples. In the present study, Shigella spp., ranged from 0 CFU/100ml to 7 CFU/100ml with a median of 0 (0) CFU/100ml. The majority of the water points were had no Shigella in them only 3% of the samples had Shigella above the WHO standards.

Salmonella spp. was present in 38% of the samples and the counts ranged from 0 and 110 CFU/100ml with a median count of 0 (0) CFU/100ml. The organism was detected in 38% of the samples throughout the rainy season. During the dry season, Salmonella counts ranged from 0 CFU/100ml to 78 CFU/100ml with a median value of 0 (0) CFU/100ml. Salmonella was present in only 8% of the samples.

4.6 Correlation Matrix Evaluation and Seasonal Variation

The correlation between water quality parameters is reported in Tables 14 and 15. During the rainy season there was a strong positive correlation between Total Coliform and E. coli ($r = 0.9653$, $p = 0.0000$), EC and TDS ($r=0.9995$, $P= 0.0000$) and EC and F^- ($r= 0.7006$, $p = 0.0000$) whereas TC and FE, Salmonella and TC and E. coli and Salmonella, revealed moderate correlation respectively ($r = 0.4311$, $p = 0.0018$, $r= 0.4681$, $p= 0.0006$ $r = 0.4926$ $p = 0.0003$). There was low positive correlation between Salmonella and Shigella, $r = 0.2562$, $p= 0.0725$; p

< 0.05). There was a low negative correlation between TC and EC (r = -0.2572, p= 0.0714), TC and TDS (r = -0.2565, p= 0.0721).

During the dry season, a positive correlation was observed between TC and E. coli, EC and TDS respectively (r = 0.7774, p = 0.000, r = 0.9981, p = 0.0000). There was a moderate positive correlation between TC and FE (r = 0.4994, p = 0.0002). A low positive correlation between was observed between EC and F^- (r= 0.3654, p= 0.0091), EC and NO_3^- (r= 0.3560, p=0.0112) and TDS and NO_3^- (r=0.3568, p= 0.0110).

Table 14. Correlation matrix Spearman (r) and alpha (p) values for the rainy season

Parameters	TC	FE	E. coli	Salmonella	Shigella	pH	Temp.	EC	TDS	F^-	NO_3^-	As	Hg
TC	1												
FE	0.4311	1											
E. coli	**0.9653**	0.4537	1										
Salmonella	**0.4681**	0.1914	**0.4926**	1									
Shigella	**0.3507**	-0.0900	0.2877	0.2562	1								
pH	-0.0165	0.1194	0.0053	-0.1596	-0.1407	1							
Temperature	-0.0249	0.0288	-0.0131	0.0421	-0.0914	-0.0045	1						
EC	-0.2572	0.0855	-0.1727	-0.2069	-0.1653	0.1117	0.3291	1					
TDS	-0.2565	0.0877	-0.1738	-0.2123	-0.1617	0.1072	0.3244	**0.9995**	1				
F^-	-0.1941	-0.0535	-0.1571	-0.2188	-0.0050	0.4246	0.0780	**0.7006**	**0.7005**	1			
NO_3^-	-0.1870	-0.0423	-0.2197	-0.0261	0.0392	0.0174	0.3275	**0.4937**	**0.4921**	0.2522	1		
As	-0.0685	0.0091	-0.0897	-0.0404	0.2176	0.2724	-0.1665	**0.3597**	**0.3637**	**0.5411**	0.1989	1	
Hg	-0.2894	-0.1500	-0.3224	-0.0087	-0.0343	-0.3020	**0.3387**	0.0794	0.0781	-0.0508	0.3180	0.0214	1

Values in bold are different from 0 with significance level alpha =0.05

Table 15. Correlation matrix Spearman (r) and alpha (p) values for the dry season

Parameters	TC	FE	E. coli	Salmonella	Shigella	pH	Temp.	EC	TDS	F^-	NO_3^-	As	Hg
TC	1												
FE	**0.4994**	1											
E. coli	**0.7774**	0.3961	1										
Salmonella	0.3014	0.3897	0.3496	1									
Shigella	-0.0207	-0.0256	0.0716	0.2220	1								
pH	0.1446	-0.0288	0.1434	0.0587	-0.1229	1							
Temperature	-0.0929	0.0842	-0.1506	-0.2388	-0.2102	-0.0574	1						
EC	-0.1254	-0.1054	0.0667	-0.2003	0.0952	-0.2523	0.0496	1					
TDS	-0.1389	-0.1026	0.0552	-0.2059	0.0952	-0.2448	0.0553	**0.9981**	1				
F^-	0.0438	-0.1134	-0.0278	-0.3359	0.0075	0.2262	0.0878	**0.3654**	0.3680	1			
NO_3^-	-0.0037	-0.2245	-0.0246	-0.2940	-0.2192	0.0179	0.1520	**0.3560**	**0.3568**	0.2494	1		
As	-0.1804	0.0348	-0.1529	0.0385	0.0237	0.1386	0.0880	**0.0293**	**0.0259**	-0.2223	0.1383	1	
Hg	0.0222	-0.0279	-0.0761	-0.1173	-0.1219	0.1238	-0.1155	-0.0132	-0.0206	0.1493	0.0096	0.0237	1

Values in bold are different from 0 with significance level alpha = 0.05

4.7 Seasonal variation in water pollutants

The analysis revealed significant deterioration in water quality in almost all the sources of water during the rainy season. The study revealed a strong negative impact of rains on microbiological contaminants. The Z- statistics for Total coliform was (Z= 3.379, p = 0.0007), this indicates that the coliform levels in the rainy season are higher than those in the dry season. Thus, there is a statistically significant difference between total coliform levels in the rainy season and the dry season. Fecal Enterococci deteriorated during the rainy season (Z=4.270, p = 0.0000), There was higher in E. coli, Salmonella and Shigella during the rainy season respectively (Z= 5.410, p = 0.0000, Z= 3.602. P= 0.0003 and Z= 3.726, p= 0.0002).

All the physico-chemical parameters, and some of the chemical parameters had lower concentration during the rainy season compared to the dry season. pH levels in the dry season tend to be higher in the dry season compared to the rainy season (Z = -2.220, p = 0.0264). Temperature was also higher during the dry season than the rainy season (Z= -9.223, P= 0.0000). TDS of the water was significantly lower in the rainy season (Z = -2.133, p = 0.0329) (Table 13).

4.8 Differences in water pollutants between main water source and household stored water

The analysis conducted on the median difference in water quality parameters among water source and households revealed significant deterioration in some water quality parameters in household. Distance to water source, water collection container, and water storage all influence water quality. The analysis indicated that during the rainy season, there was a significant difference in the level of TC, FE and E. coli at the main source and at the household (z = -2.337, p = 0.0195), (z = -2.100, p = 0.0357), (z = -2.907, p = 0.0037) respectively. Levels at the household were higher than at the main source. Levels of Mercury, EC TDS and Nitrate also showed significant difference at the main source and household (z = 2.279, p = 0.0227), (z = 2.140, p = 0.0323), (z = 2.130, p = 0.0332), (z = 2.315, p = 0.0206) respectively.

The dry season did not indicate significance in most of the contaminants. For microbial contaminants only TC had levels higher at the household than the main source (z = -2.073, p = 0.0382). For physico-chemical properties only pH was higher at the household compared to the main source (z = -2.152, p = 0.0314) (Supplementary table 3a and 3b).

4.9 Water Quality Index

During the rainy season, based on the water quality index, 2 % of the water points was of excellent quality, 18% was of good quality, 12% was of fair quality, 62% displayed marginal quality and the remaining 6% was of poor quality.

Water quality improved in the dry season because there was an increase from 18% during the rainy season to 30% during the dry season. During the dry season water of excellent quality still stood at 2%. Water of fair quality increased from 12% in the rainy season to 24% during the dry season was of fair quality while 36% was of marginal quality and 8% reflected water of poor quality.

For both seasons, 46% of the water from Shia exhibited marginal water quality, 27% showed good quality, 18% also displayed fair quality while the remaining 9% indicated poor quality.

None of the water samples from Balungu showed excellent water quality. Twenty-one percent 21% of the water samples revealed good quality, 50% were of marginal quality 25% indicated water of fair quality and 4% were of poor quality.

About 42% of the samples from Gbane Obuasi revealed water of marginal quality, 25% demonstrated water of good quality, 19% were of fair quality, 7% displayed excellent quality and the remaining 7% also indicated poor quality.

Water samples from Gbane Kejetia indicated 58.3 % having marginal water quality, 25% had good quality while 12.5% showed fair quality and 4.2% revealed water of poor quality (Supplementary Table 4a).

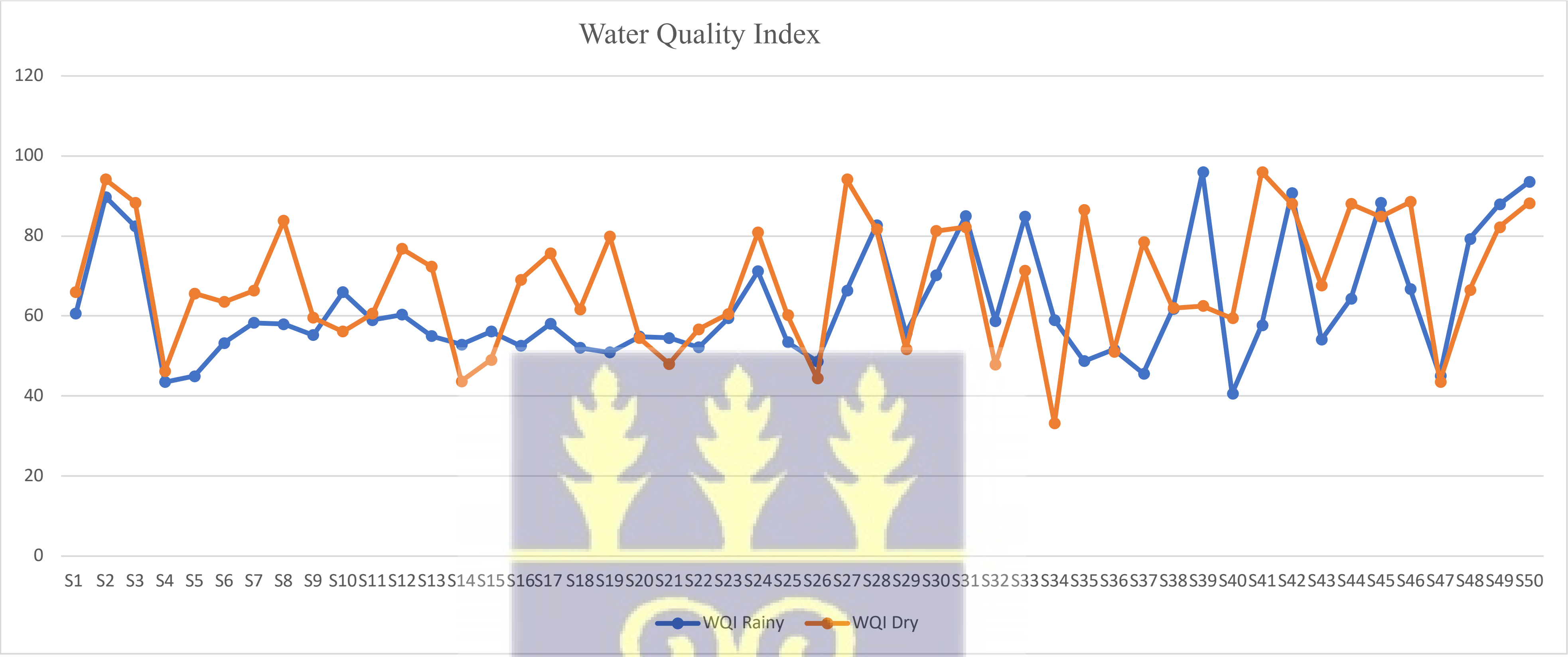


Figure 8: Comparison of water quality index for rainy and dry season

◦

To conduct sanitary inspection of water sources fand human health risk assessment among residents in Talensi District.

4.10 Sanitary Inspection

A total of 92 water points consist of 26 boreholes and 66 household water points. were tested for both seasons in this study.

The sanitary hazard index of the water points during rainy seasons revealed that 64% were classified as very high risk of Total Coliform contamination based on the established threshold by WHO and required agent action to rehabilitate water sources. Furthermore 24% were categorized high as risk and 12% as low risk. During the dry season, bacteriological testing revealed that 34% of the sites had Coliform counts greater than 100 CFU/100mL, while 42% had Total Coliform counts ranging between 11 and 100 CFU/100mL and 12% had low risk.

Table 10. Combining sanitary inspection and water quality monitoring: prioritizing surveillance efforts and interventions for the rainy season

Total Coliform (CFU/100ml)	Sanitary inspection risk score			
	0-2	3-5	6-8	9-10
>100	0	6	21	5
11-100	0	4	8	0
1-10	0	0	0	0
0	6	0	0	0

Low risk: No action required	**Intermediate risk: low action priority**	**High risk: higher action priority**	**Very high risk: urgent action required.**
12%	**0%**	**24%**	**64%**

Table 11. Combining sanitary inspection and water quality monitoring: prioritizing surveillance efforts and interventions for dry season

Total Coliform (CFU/100ml)	Sanitary inspection risk score			
	0-2	3-5	6-8	9-10
>100	0	4	8	3
11-100	0	2	18	2
1-10	0	0	1	0

0	12	0	0	0

Low risk: No action required	**Intermediate risk: low action priority**	**High risk: higher action priority**	**Very high risk: urgent action required.**
24%	**0%**	**42%**	**34%**

4.10.1 Human Health Risk (Chemical Risk Assessment)

The hazard indices (aggregate risk) are presented in supplementary Table 5. The ranges of HI for As, Hg and F^- of all the sampling locations during the rainy season varied from 0.0013 – 3.01. In the dry season, it ranged from 0.049 to 5.37. The hazard index for As and NO_3^- ranged from 0.003 – 3.22 during the rainy season while the dry season fluctuated from 0.0016 – 4.97. The target organ of Arsenic, Mercury and Fluoride is the kidney and 16% of the sample points during the dry season had HI values exceeding the safe limit of less than 1 (<1). A smaller portion of the water points 2%) had HI above the safe limit.

For Arsenic and Nitrate, the target organ is the liver. The calculated hazard indices revealed that 10% of the sample's points were above the safe limit in the dry season and 2% were recorded in the rainy season. Since some of the water points had hazard indices above the1.0 threshold, these water points are not safe for consumption.

To assess the carcinogenic risk, the daily intake of Arsenic in water by the local population was evaluated using the concentration of Arsenic in the water samples from the study area. The findings indicated that the levels of arsenic detected in the water samples posed a significant carcinogenic risk to the residents of the study area. In the rainy season the carcinogenic risk ranged between 2.14E-06 to 6.64E-04. About 16% were below the detection limit, 14% of the samples were within the optimal range of 10^{-6}, and 70% were above the threshold. For the dry season, 60% were below detection limit, 8% were within the threshold while the remaining 32% were above the threshold.

All the water points had Hg contaminants below WHO guidelines. Its presence in water is a serious problem because it is a persistent and lipophilic and can bioaccumulate in the human body (Tanabe *et al*., 2000; Kishimba, 2004). Therefore, its presence in water is not good for human consumption.

4.10.2 Quantitative Microbial Risk Assessment

The average number of bacteria ingested was calculated. The highest ingestion doses per day were from Shigella spp., followed by Salmonella spp., and then E. coli. (Table 27). The highest number of E. coli ingestion per day was detected in Shia, while lowest was Gbane Obuasi. Shigella ingestion was highest in Gbane Kejetia and the lowest in Shia during the dry season. Salmonella ingestion was highest in Gbane Kejetia during the dry season and lowest in Balungu. Further analysis on the probability of infection per day and per year was conducted by demographic area, seasonal and source of water. The highest risk due to E. coli was estimated for residents who use surface water for drinking purposes in Gbane Kejetia (22%) and Gbane Obuasi (20%) during both the rainy and dry seasons. The Risk for Salmonella spp. was highest in surface water in Gbane Kejetia and Gbane Obuasi (19.4%) and (11.1% respectively).

The probability of infection per year was analysed across all communities, and drinking water for residents was estimated to lead to an extremely high risk of infection by each bacterium assessed. The probability of infection from Shigella was 30% during the rainy season and 8% during the dry season. About 38% of the residence were at risk of illness due Salmonella spp. during rainy season and 10% during the dry season. About (82%) were at risk of illness due E. coli during the rainy season and 32% during the dry season.

Exploring sanitation access of residents in the Talensi district revealed that, many community members in both mining and non-mining areas do not have access to toilet facilities and hence resort to open defecation. For instance, some participants stated that:

The alarming nature of open defecation in the district and its effect on the natural water sources in the communities was also expressed by some participants. For instance, a respondent expressed his sentiment in the following words:

> *I know open defecation is a serious challenge in this district and it's possible most of our water bodies may be contaminated with faecal matter. There was a UNICEF report that indicated that almost 60% of the boreholes fitted with hand pumps in the district were contaminated with faeces.* ***(KII, Male, Office 8)***

The risk of illness due to each of the bacteria had significant variation within household and main source. The risk of illness due to water stored in the household was higher compared to the main source. The risk of illness due to E. coli at the household was higher at the household (64%) than the main source (18%). The risk of illness due to Salmonella was 12% in the main source and 28% at the household. The risk due shigella was higher at the household (20%) than main source (12%) thought out the rainy season. Whereas in the dry season the risk of illness due to E. coli was (12%) at the main source and (24%) at the household. Water from household containers collected from the various sources of water yielded the highest annual risk of infection and disease burden due to E. coli with a risk of (64%) at the household level and 18% at the main source.

A major part of the annual risk of infection originated from Shigella (9.89×10^{-1}), was from the household and the least important contributor was E. coli at the main source. The probability of infection for the E. coli, Salmonella spp., and Shigella Spp., was determined for all the sources of water. The annual risk of infection from E. coli for water from the boreholes and reservoirs was lower (1.70×10^{-3} and 1.20×10^{-3}) than that from the stream (7.85×10^{-3}).

The calculated risk of infection due to Salmonella spp. was much higher in water from the stream (7.00×10^{-1}) compared to that from the borehole (1.10×10^{-1}). The risk of infection for shigella was very high in water from the stream (9.99×10^{-1}).

The differences in risk of infection per year between water taken from different communities revealed that water from Gbane kejetia has the highest risk of infection of from E. coli (6.00×10^{-3}), the risk in the other communities were the same (4.15×10^{-3}). Risk of infection associated with Salmonella was lower in all the communities, but the highest was recorded in Balungu (9.88×10^{-2}), followed by Gbane Kejetia (2.86×10^{-1}) then Gbane Obuasi (2.08×10^{-1}) and then Shia (1.99×10^{-1}). Risk of infection due to shigella was very high in all the communities but the highest was recorded in Gbane Kejetia (9.89×10^{-1}), followed by Gbane Obuasi (9.7×10^{-1}), Shia (9.3×10^{-1}) then Balungu (9.10×10^{-1}).

The calculated levels of disease burden associated with E. coli, Salmonella and Shigella from the borehole, stream and reservoir were compared to WHO reference level of risk (10^{-6} DALY) (WHO, 2012). The disease burden from the stream associated with Salmonella, Shigella and E. coli (8.74×10^{-4}, 2.84×10^{-4}, $5.02. \times 10^{-5}$) respectively was higher than the risk posed by the water from the reservoir. The disease burden from the borehole associated to Salmonella (1.24×10^{-2}), Shigella (2.04×10-2) and E. coli, (9.79×10^{-5}) was all higher than the WHO reference level of tolerable risk. The high levels of microbes in the drinking water can indeed be attributed to the practice of open defecation. From the study, 65% of the total respondent in the study area practice open defecation.

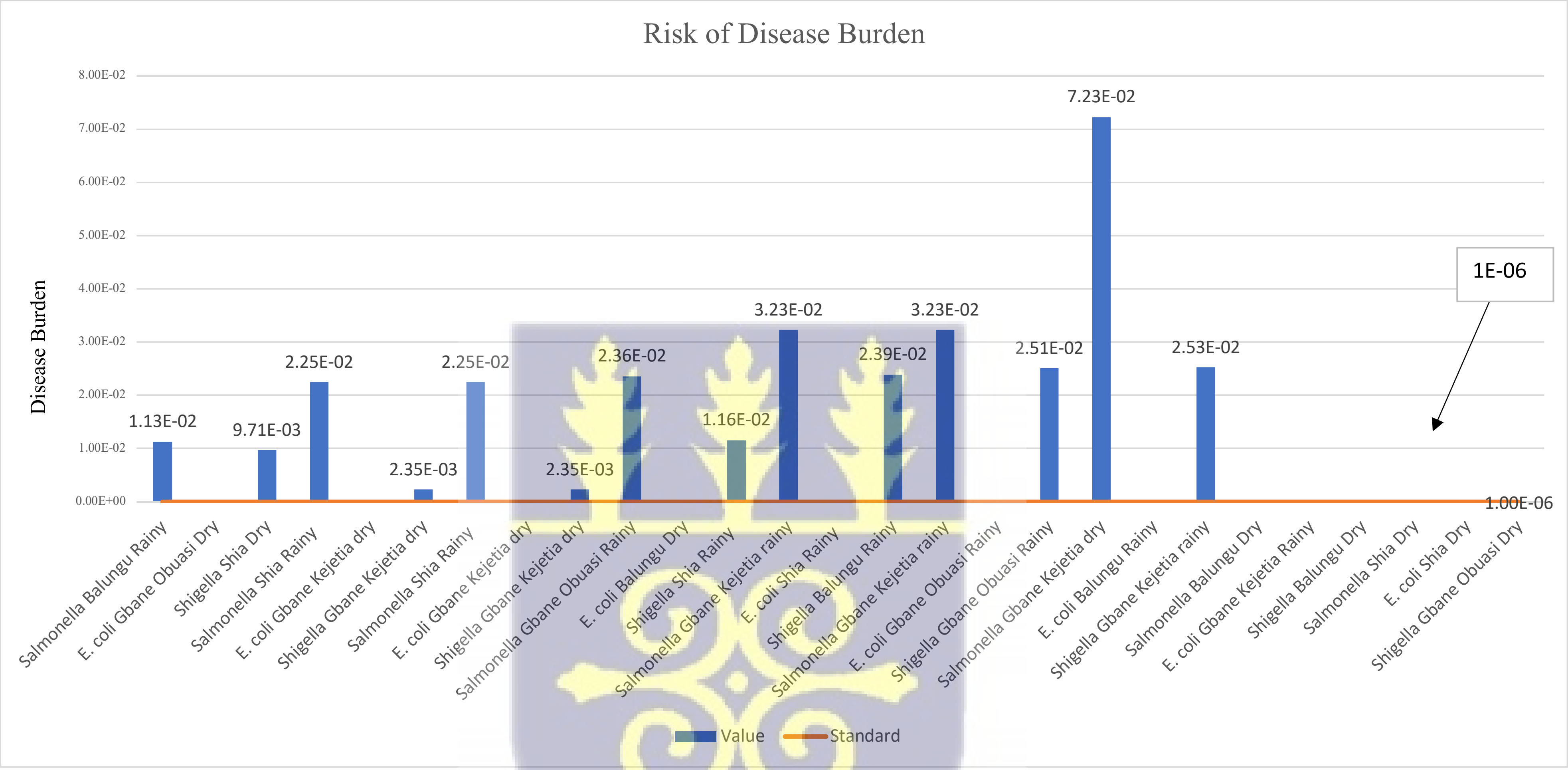


Figure 9: Graph showing the risk of disease burden in the four communities.

To determine the extent of land use/land cover change on water quality, surface modelling of water pollutants and estimated population at risk.

4.11 Land Use/Land Cover

The vegetation class stood as the most dominant LULC type in the district in both survey seasons with a surface area of 407.80 km^2 (48.01%), and 357.89 km^2 (42.14%) during the rainy and dry season respectively. The second dominant type was Bare land which occupied 218 km^2 (26%) during the rainy season and increased to 313.98 km^2 (36.97%) during the dry season. Water occupied 122.31km^2 (14.40%) of Talensi's landscape during the rainy season. It declined in the dry season to 76.67km^2 (9.02%). Built-up land cover represented 100.74 km^2 (12%) in the rainy season and 100.79 km^2 (12%) during the dry season.

Based on the classified pixels, it was observed that in the dry season water decreased by 37%. A focus group discussant talked about their source of water drying up in the dry season.

> *In the dry season, the stream dries up, so we dig in the stream way and wait for water to spring up and then fetch. This is time consuming because you must wait for the sand to settle before you can fetch it.* ***(R3, Female, Community 1FDG)***.

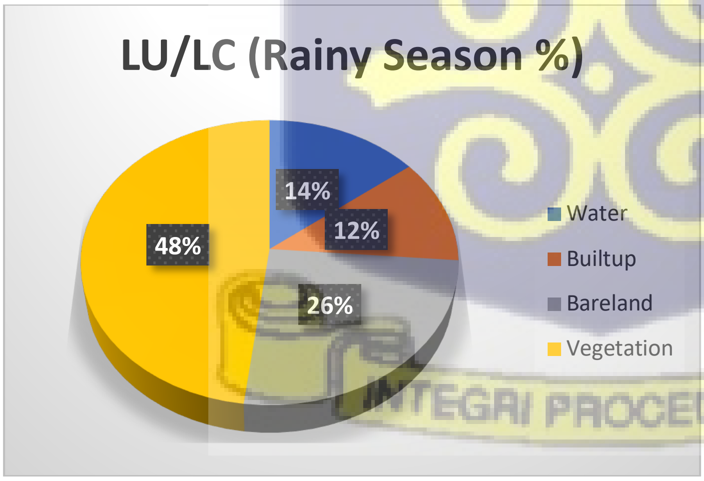


Figure: 9 percentage of LULC for rainy season

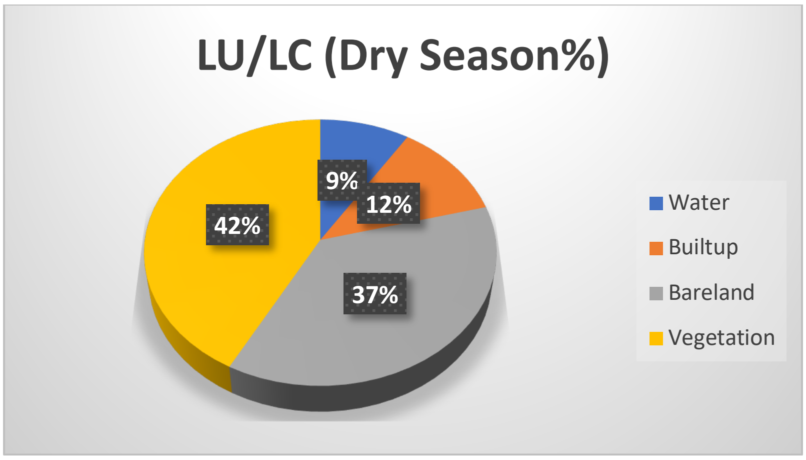


Figure: 10 percentage of LULC for dry season

Table 16: Change Matrix of LULC in Talensi between Rainy Season and Dry season.

Dry Season Km^2 Rainy Season KM^2		Bare land	Built up	Vegetation	Water	Row Total
	Bare land	**38.59**	14.59	96.45	2.11	151.73
	Built up	34.53	**137.90**	50.52	43.48	266.42
	Vegetation	117.03	31.14	**172.17**	10.32	330.66
	Water	9.62	28.21	25.64	**36.59**	100.06
	Class Total	199.76	211.84	344.77	92.50	848.87
	Class Changes	161.18	197.25	248.33	90.39	
	Image difference	11.20	0.01	-5.87	-5.37	

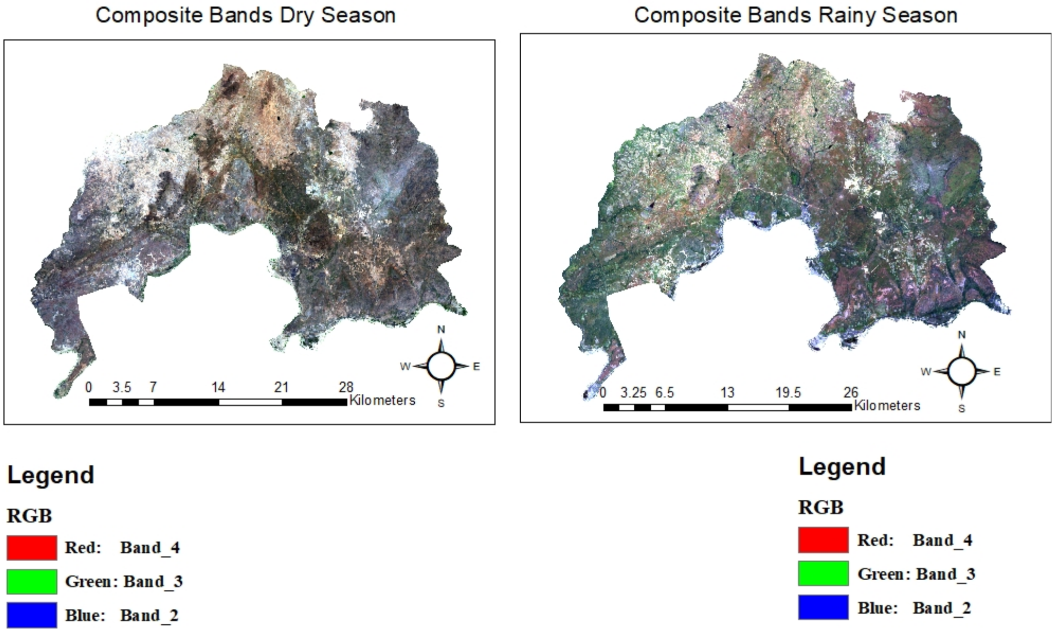


Figure: 11 Land Use/ Land Cover composite band of natural colours map for both season

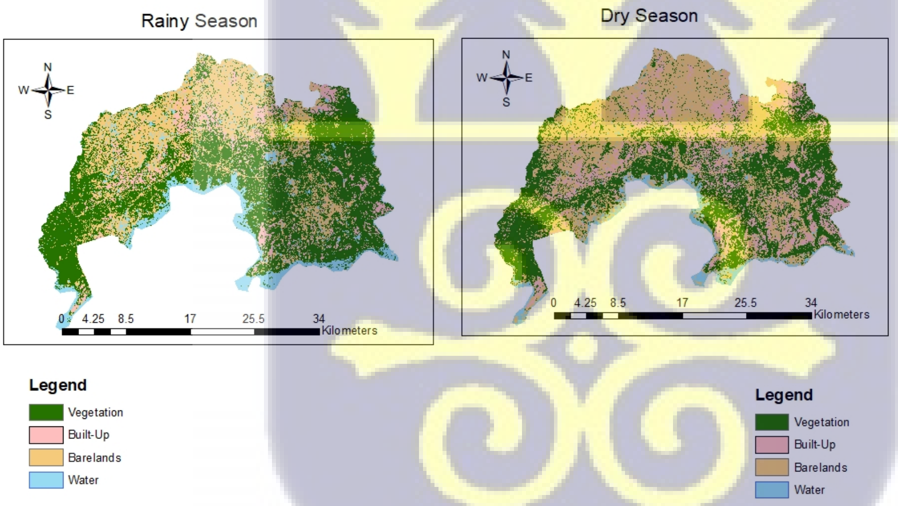


Figure: 12 Land Use/ Land Cover map for both season

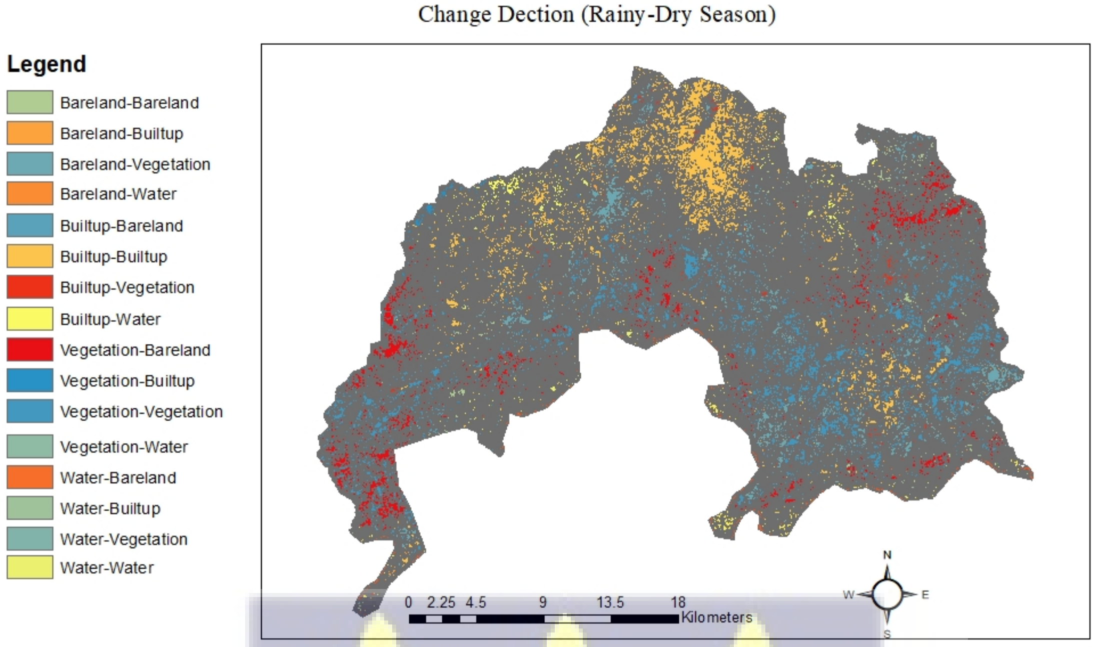


Figure: 12 Change detection map.

4.12 Surface Interpolation

The Inverse Distance Weighting, in ArcGIS V.10.8, was used to predict WQI and Fluoride levels in the study area for both seasons. The water quality map of each survey season showed areas having poor to excellent water quality for human consumption. During the rainy season the western part, that is where Balungu and Shia are located had marginal water quality with a little area showing fair and good water quality. Also in the same season, the eastern part where Gbane Kejetia and Gbane Obuasi are located, had a large portion showing marginal water quality with and minor portions having fair and good water quality.

In the dry season, most of the water points from the eastern part improved from marginal to fair water quality. For the western only Balungu had improved water quality from marginal to fair. Most of the water points in Shia still had marginal water quality.

Geospatial surface modelling for Fluoride was carried out in the study area. This analyte was selected for spatial modelling because of concerns from the Talensi district office.

The Western part of the district where Shia is located had troubling fluoride values in both survey season. One male participant from KII remarked:

> *"...There is another challenge in some of our communities with reference to a high level of fluoride. We have not yet established it, but we have seen the signs. We want to determine the levels at the laboratory because we can see them on the children. The teeth of the children are becoming brown. So, if we get the laboratory results, we will know what to do..."* ***(KII, Male, Office 4).***

The hazard map generated showed that the people residing in the north-western part of the district were at high risk. About 7km^2 of the study site contained fluoride levels above the WHO reference standard during the rainy season while 5 km^2 during the dry season had fluoride levels above the WHO guidelines. A total of 438 children between the ages of 0-15 years were at risk as a results of Fluoride exposure during the dry season while 516 children were at risk during the rainy season. In total, an estimate of 1950 people were potentially exposed in the study area during the dry season and 2012 people were exposed during the rainy season.

4.12.1 Accuracy Assessment for Image Classification

The classification performed in the rainy season (September, 2021) was accurate (97%) and reliable compared to the dry season (95%). Even though one model performed better than the other, they both performed extremely well in classifying the data and is very reliable. The high Kappa coefficient supports that the model's performance is not just due to chance but reflects a true alignment with the actual outcomes. A kappa coefficient of K > 0.80 represent strong agreement and good accuracy. 0.40-0.80 is middle, <0.40 is poor.

Table 17. Error Matrix for September 2021 classification

Classified	Bare lands	Built-up	Vegetation	Water	Classified Totals
Bare lands	58	0	1	1	60
Built-up	0	44	0	1	45
Vegetation	1	0	44	0	45
Water	1	1	1	47	50
Reference Total	**60**	**45**	**46**	**49**	**200**

$$\mathrm{K} = \frac{\big(200 * \ (58 + 44 + 44 + 47)\big) - (\,(60 * 60) + (45 * 45) + (45 * 46) + (50 * 49))}{200^2 - (\,(60 * 60) + (45 * 45) + (45 * 46) + (50 * 49))}$$

$$\mathrm{K} = 0.95$$

Dividing the number of correctly identified pixels by the total number of sampled pixels yields the overall accuracy (OA).

$$\mathrm{OA} = \frac{(58 + 44 + 44 + 47)}{200}$$

$$\mathrm{OA} = 0.97$$

Table 18. Error Matrix for February 2022 classification

Classified	Bare lands	Built-up	Vegetation	Water	Classified Totals
Bare lands	62	1	1	2	66
Built-up	0	49	0	1	50
Vegetation	1	0	46	0	47
Water	2	1	2	47	52
Reference Total	**65**	**51**	**49**	**50**	**215**

$$\mathrm{K} = \frac{\big(215 * \ (62 + 49 + 46 + 47)\big) - (\,(66 * 65) + (50 * 51) + (47 * 49) + (52 * 50))}{200^2 - (\,(66 * 65) + (50 * 51) + (47 * 49) + (52 * 50))}$$

$$\mathrm{K} = 0.95$$

$$\mathrm{OA} = \frac{(62 + 49 + 46 + 47)}{215}$$

$$\mathrm{OA} = 0.95$$

Table 19. September 2021 Confusion Matrix

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy.	Users Accuracy	Overall Accuracy	Kappa Coefficient
Bare land	60	60	58	96.7%	96.7%	0.97	0.95
Built-up	45	45	44	97.8%	97.8%		
Vegetation	46	45	44	95.6%	97.8%		
Water	49	50	47	95.9%	94%		
Colum total	200	200	193				

Table 20. February 2022 Confusion Matrix

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy.	Users Accuracy	Overall Accuracy	Kappa Coefficient
Bare land	65	66	62	95.3%	95.4%	0.95	0.95
Built-up	51	50	49	96.0%	98%		
Vegetation	49	47	46	93.9%	93.9%		
Water	50	52	47	94%	90.4%		
Colum total	215	215	204				

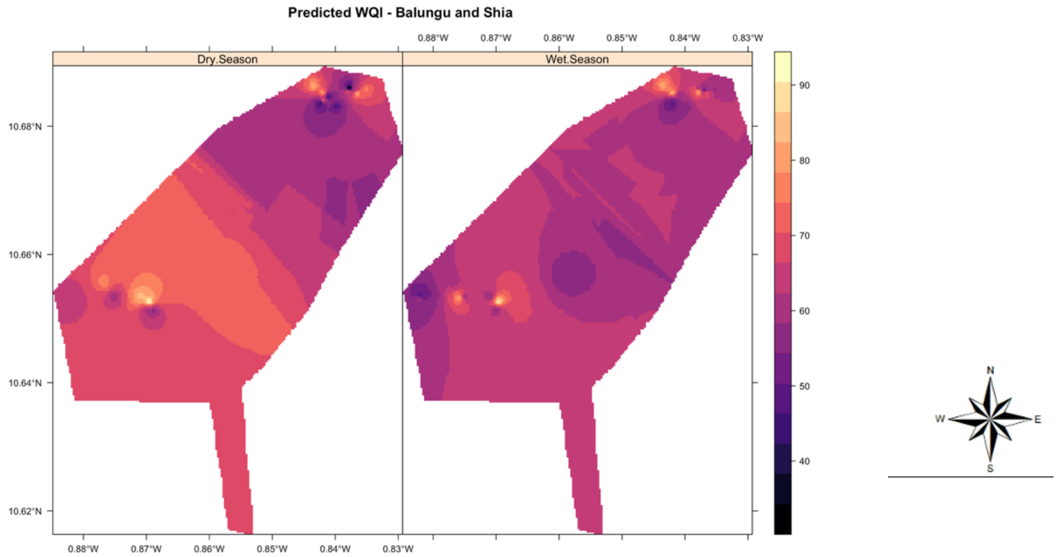


Figure: 13 Spatial modelling and prediction for water quality

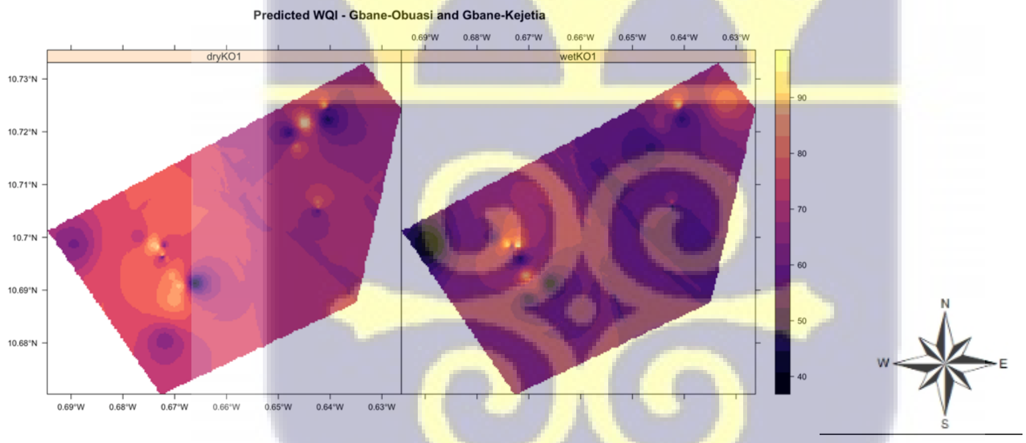


Figure: 14 Spatial modelling for water quality

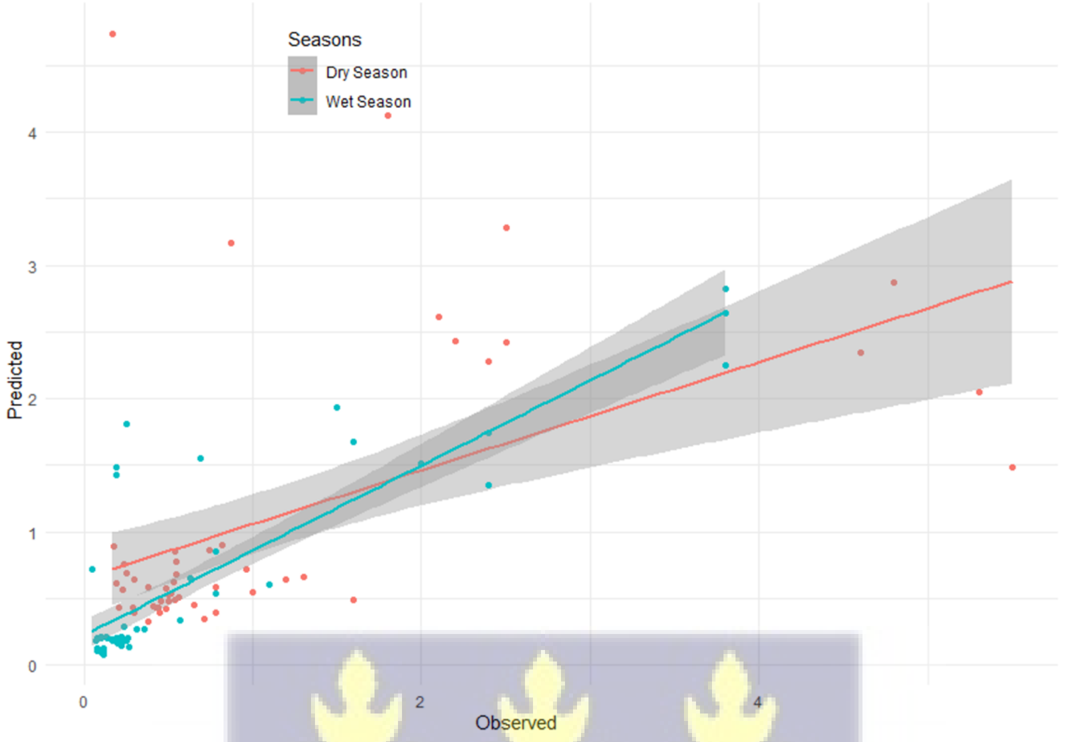


Fig. 15 Scatter plot of measured and predicted water quality

Table 21. Goodness of fit metrics of Interpolation for water quality

Season	ME	MAE	MSE	RMSE	Pearson - R
Dry	0.28	1.55	2.83	1.68	0.81
Wet	0.06	1.98	4.95	2.23	0.69

The mean error 0.28 slightly overestimated the true values for the dry season as well as the mean error for the rainy season. The absolute difference between the dry season model predictions and the true values is about 1.66 units and 1.98 for the rainy season. The correlation coefficient of 0.81 for the dry season indicates a positive linear relationship between the dry season model predictions and the true values. The wet season model had a coefficient of 0.69. Similarly, there is a positive linear relationship between the wet season model's predictions and the true values, but the strength of the relationship is lower compared to the dry season's model. Overall, both models showed some level of predictive performance, but the dry season model seems to better perform slightly better across most metrics. It has lower error metrics

(MAE, MSE, RMSE) and a stronger correlation coefficient. The wet season model, while still providing relatively accurate predictions, exhibited higher errors and a weaker correlation.

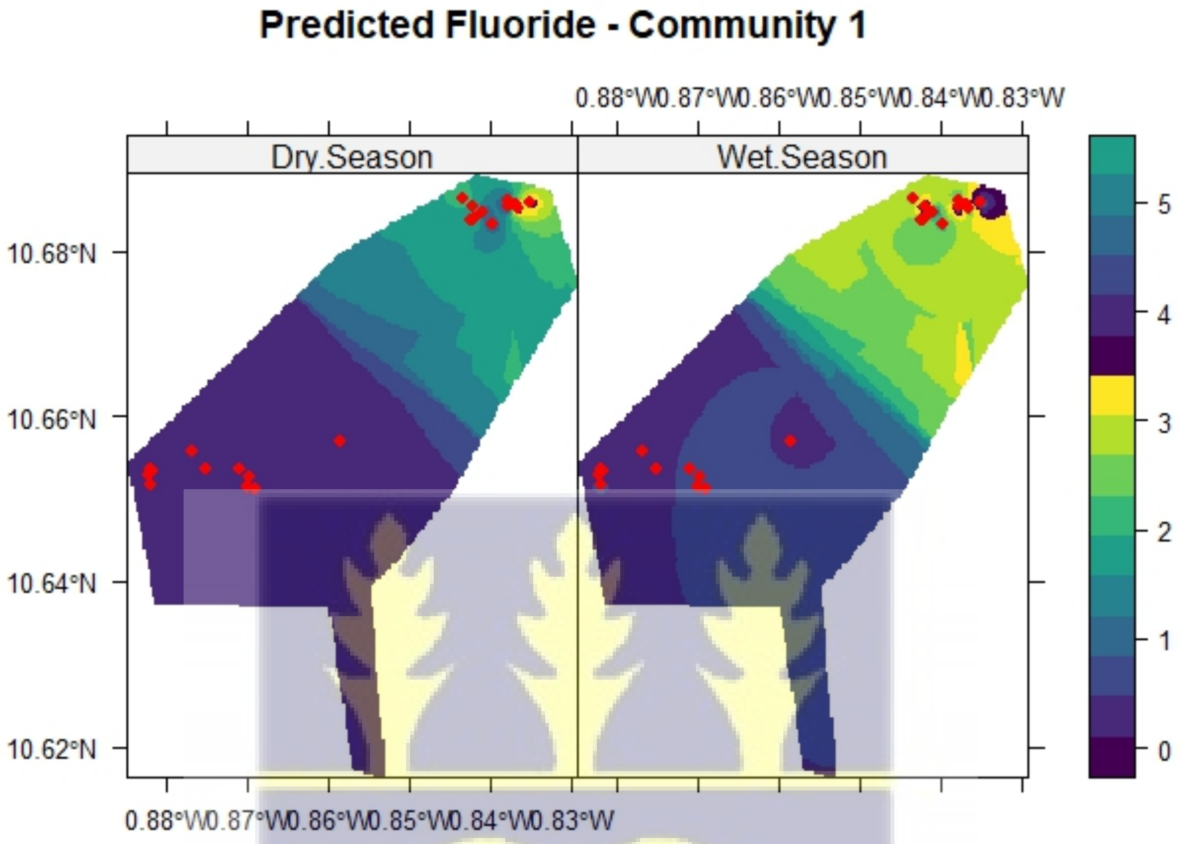


Figure: 14 Spatial modelling for Fluoride in water

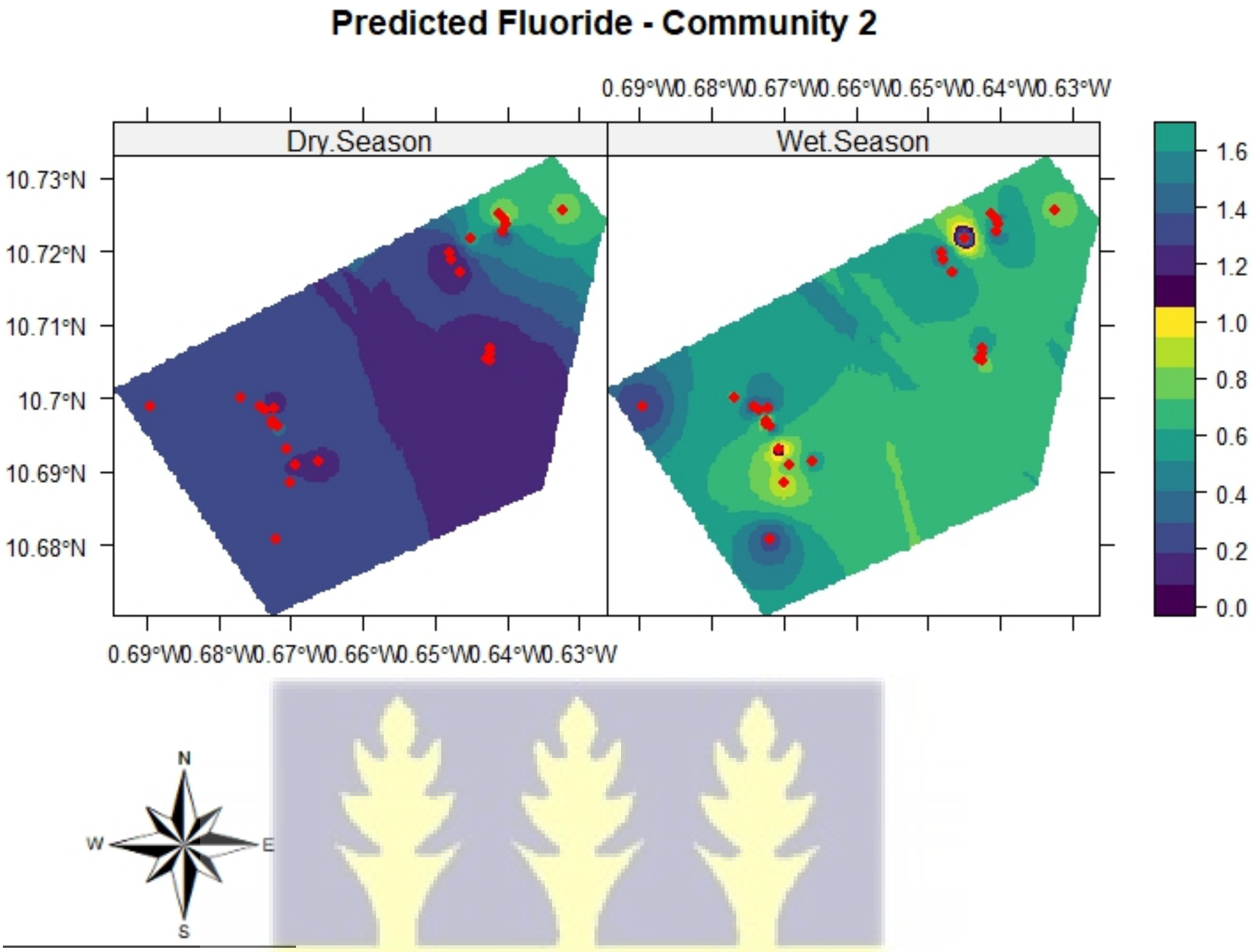


Figure: 15 Spatial modelling for Fluoride in water

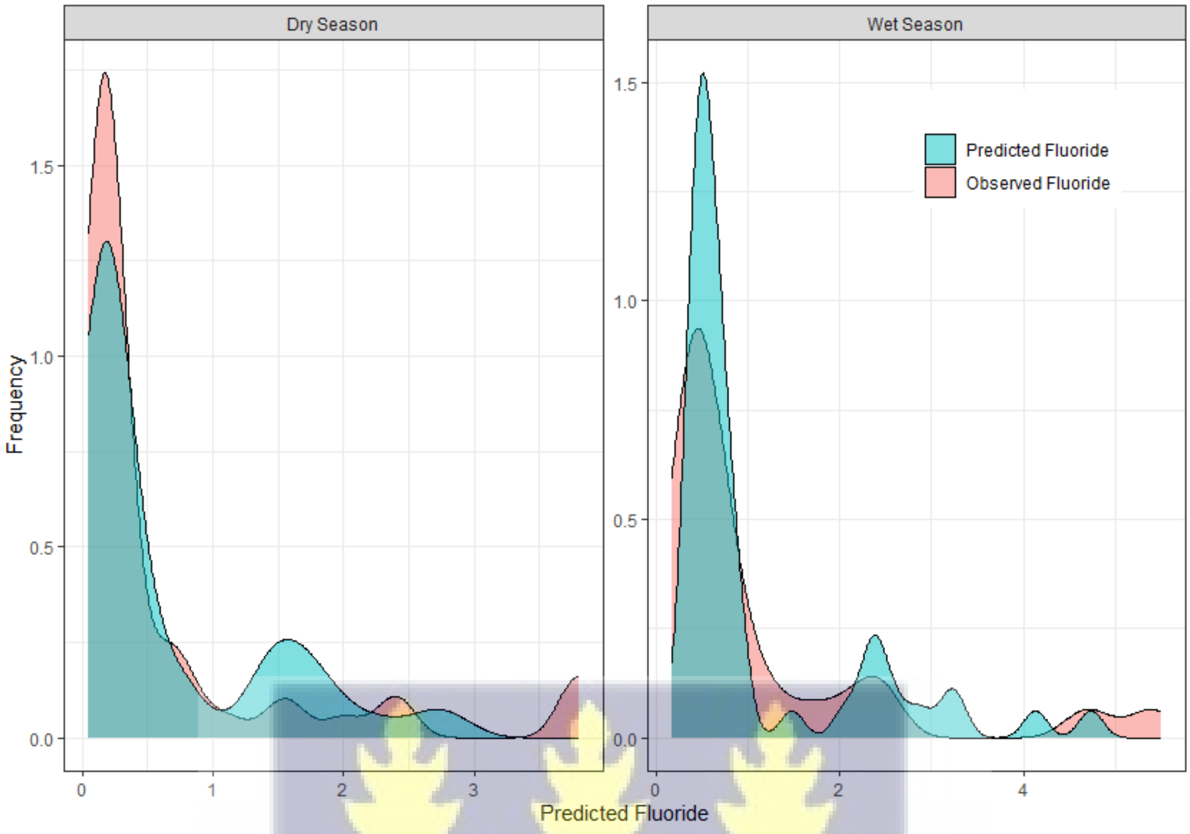


Figure: 16 Density plot of measured and predicted Fluoride

Table 22. Goodness of fit metrics of Interpolation for fluoride

Season	ME	MAE	MSE	RMSE	Pearson - R
Dry	0.01	0.29	0.28	0.53	0.85
Wet	0.02	0.63	1.45	1.2	0.51

During the dry season, the mean error is approximately 0.01. On average, the interpolation model's predictions are very close to the true values for the dry season. Also, the mean error for is about 0.02. Similarly, for the wet season, the model's predictions are also quite close to the true values. The absolute error for the dry season is around 0.29, the absolute difference between the interpolation model's predictions and the true values is about 0.29 units for the dry season. For the rainy season, the mean absolute error is approximately 0.63 and the difference between the prediction and the true values is about 0.63units. The means square error which calculates the average of squared difference between the interpolation model's predictions was 0.28 during the dry season and 1.45 for the rainy season. The average magnitude of prediction error (Root Means Square Error) was 0.53 during the dry season and 1.2 during the rainy season.

The Pearson- R (Pearson Correlation Coefficient is about 0.8 for the dry season. This indicates a strong positive linear relationship between the interpolation model's predictions and the true values for the dry season. A value of 0.51 for the season indicates a moderate positive linear relationship between the predictions and the true values for the wet season.

CHAPTER FIVE

DISCUSSION

5.0 Introduction

This chapter focusses on the discussion of the key findings. It compares the study findings with other existing literature and aims to highlight the key findings. The following sub-topics are narrated according to the study objective and summary of key findings of the study; discussion of households' access to improved water during both survey seasons; water quality analysis, water quality index, human health risk assessment, geospatial modelling of water pollutants; Land Use/Land Cover of Talensi; generalisation and transferability of the study findings; strength and limitations of the study; lessons learnt from fieldwork about feasibility; and the implications of the study findings.

5.1 Determinants of household's access to improved water sources

5.1.1 Households' access to improved water sources during the rainy and dry season

Lack of clean drinking water contributes significantly to the disease burden in the country (MICS, 2018). During the dry season, households' access to improved drinking water sources declined slightly, especially in the mining communities. One plausible reason to the decline in water during the dry season is that, most of the people in the mining areas depend on rain water and streams as well as water tankers brought to sell in the communities from other towns. Because mining activities in those communities have gone deeper than the boreholes that were drilled, the boreholes in this area does not yield any water when you pump. Also, during the dry season, zero rains are recorded making it difficult to access rain water. Likewise, most of the people do not buy water from the tankers because its expensive therefore people resulting to digging hole in water ways and wait for water to spring up before fetching.

This is in contrast with a study by Abebaw et al. (2011), which did not find any significant seasonal variability in terms of access to improved water sources. Also, the study observed a higher time in collecting water during the dry season. One plausible reason for this is that during the dry season, most of their water sources, such as streams and boreholes, dry out, and residents must dig holes in the streamway and wait for water to spring up before fetching, which can be time-consuming. The unequal distribution of access to improved water sources is a significant challenge faced by many people living in various parts of the world. In many rural areas, collecting water is a daily struggle and can consume a considerable amount of time and effort, especially during the dry season when the water sources dry up or during other conditions such as drought or water scarcity. Findings from the study also revealed that the price of water plays a crucial role in determining the accessibility of improved water sources for residents in Talensi, particularly the mining areas. People in the mining areas resort to alternative means of obtaining water, such as fetching it from nearby streams or rivers. The decision to fetch it from these sources instead of purchasing it is primarily driven by financial constraints.

Concerning the types of drinking water services used by respondents in the study location, according to the data, during the rainy season, 33.03% of the respondents used an improved drinking water source that was accessible on their premises. However, this number significantly dropped to 2.55% during the dry season. On the other hand, 24.22% of the respondents used basic drinking water services; this implies that they had access to an improved source but had to travel for not more than 30 minutes to reach it during the rainy season. However, in the dry season, 49.49% of this group had to travel for not more than 30 minutes, including queuing for water, indicating that the improved water source was not easily accessible for them. A further 47.96% of the respondents used limited services, which means they had access to an improved source but had to travel for more than 30 minutes to reach it during the dry season. This reduced to 24.22% during the rainy season. This group faced even more significant challenges in accessing safe drinking water, which can pose risks to their health. Finally, 9.17% of the respondents used water from an unimproved source, suggesting that they did not have access to safe drinking water. This group is at high risk of contracting waterborne diseases and other health risks associated with contaminated water.

Studies have shown that most rural communities in Sub-Saharan African countries do not have pipes connected to their homes, thus making access to improved water on premises difficult (Abebaw et al., 2010; Mahama et al., 2014; Simelane et al., 2020). Similarly, the amount of time spent collecting water is higher in these communities (WHO & UNICEF 2017). Lack of access to improved sources of on-premises piped water can lead to the use of more distant alternative sources. This mostly reduces the quantity fetched and compromises the quality of water as well (Mair et al., 2020). Women and children were the main people responsible for fetching water in the study area. Graham et al. (2016) also highlighted the gender difference in people responsible for water collection.

5.1.2 Factors associated with households' access to improved water sources.

Evidence of studies done in several SSA countries suggested that household heads with higher levels of education are more likely to have access to improved drinking water sources. This study found out that in both survey seasons, heads with higher education levels had a higher chance of having access to improved drinking water sources. The study also found that households located in the mining areas were less likely to have access to improved water sources during the dry season. Similarly, other communities in Ghana where illegal mining has polluted their surface water as well as underground water have been documented as having lower access to improved water sources during the dry season (Duncan 2020). Also, male headed households were less likely to have access to improved water sources during the rainy season. Comparable to other studies (Armah et al., 2018; Agbadi et al., 2019), it was discovered that female heads were more likely to have improved water access. One possible explanation for these results could be that, relative to men, most sub-Saharan African women have a greater household duty, such as cooking, cleaning, and washing of cloths and dishes, which require heavy use of water. This finding conflicts with other studies that found male-headed households were more likely to have access to improved drinking water sources (Sorenson et al., 2011; Chew et al., 2019; Simenlane et al., 2020). For instance, men in Eswatini regularly make decisions on water management even though women are responsible for fetching water. But in other traditional settings, women hold a little influence in committees for boreholes and other community water projects. In this study, the higher socioeconomic status of a household head accounts for households' access to improved water sources. This implies that rich households have better access to improved water sources. According to this study, the cost of accessing water may be a significant barrier for some households in obtaining improved water sources. It is possible that some households may not be able to afford the costs associated with installing or maintaining water infrastructure in both survey seasons. Temperature and rainfall impacted households access to improved water sources, as during high temperatures, households were less likely to have access to improved water sources. One credible reason for these results could be the reduction in water levels during high temperatures and the lack of rainfall during those times.

5.2 Assessing seasonal variability of water quality.

5.2.1 Physicochemical properties pH, Temperature, Electrical Conductivity, Total Dissolved Solids

The present study indicated that 4% of the samples were lower than WHO standards with the remaining 96% falling within the optimum range (6.5-8.5) as outlined by the established guidelines by WHO during the rainy season. The lowest pH was recorded from the rain harvested water. Contrary to these findings, a conducted in Talensi by Chegbeleh et al., (2020) recorded low pH values in groundwater.

The temperature range of water samples collected during the rainy season was within the WHO guidelines of 22-29°c; in contrast, water temperature generally increased throughout the dry season. Samples ranged from 30.1 to 31.7°c. All the samples analysed during the dry season were above the WHO standards. The levels during the dry season can be attributed to the rise in temperature during the dry season because of climate change impact (Daron, 2014). According to numerous studies, the northern half of Ghana is the most vulnerable to climate change impacts due to factors such as a lack of information about imminent natural disasters, precipitation and temperature variations, poverty, and illiteracy, among others, which increase the region's sensitivity to climatic extremes (Saito et al., 2018; Kluste et al., 2020).

Electrical Conductivity refers to the ability of water to conduct electricity and functions as an indicator of dissolved ionic solid concertation and salinity (Water Quality Standards, 2019). Water with high conductivity does not pose health risks to humans, but it can cause corrosion in industrial equipment or plumbing systems, scale buildup, mineral-like taste in drinking water, and issues with dissolved solid concentration in agriculture (Assumang & Danquah 2023). The high conductivity of water can be caused by natural sources such as minerals and rock or anthropogenic sources such as industrial activities and run-off roads. During the dry season, 70% of the total samples had conductivity levels above the WHO guideline set for drinking water. EC was higher during the dry season than the rainy season. One plausible explanation for this finding could be that during the rainy season rainwater dilutes water sources, thus the low EC levels during the rainy season. Based on the study findings, it appears that the water with low conductivity levels in the present study was harvested rainwater, with conductivity levels of 8.42µS/cm, 7.30 µS/cm, 5.99µS/cm, and 5.88µS/cm. This finding is consistent with a study conducted by Sila in Kenya, which also recorded low conductivity levels during months with high rainfall Sila, (2019). On the other hand, the conductivity values obtained in the present study were generally higher compared to the values obtained from the Densu River in Ghana (237-402µS/cm) recorded by Karikari & Ansah Asare (2003) as well as rural water sources in Kenya (32 to 7455µS/cm) obtained by Sila (2019). It is worth noting that conductivity levels in water can be influenced by various factors, such as the presence of dissolved salts, minerals, and other contaminants.

Total Dissolved Solids (TDS) is the term used to describe the inorganic salts and small amounts of organic matter present in water. The primary components are usually inorganic salts (positively charged cations such as calcium, magnesium, sodium and potassium) and negatively charged anions such as carbonate, hydrogen carbonate, chloride, sulfate, and nitrate (WHO, 2011). The main sources of TDS in drinking water originates from natural sources, sewage, urban run-offs, industrial wastewater, chemicals in the water treatment process, chemical fertilizers used in the garden and plumbing. Because water is a universal solvent, it easily picks up impurities, absorbs and dissolves particles quickly. The presence of dissolved solids in water may affects its taste (Devesa, 2018). The palatability of drinking water has been rated by panels of tasters in relation to its TDS level as follows: excellent, less than 300 mg/litre; good, between 300 and 600 mg/litre; fair, between 600 and 900 mg/litre; poor, between 900 and 1200 mg/litre; and unacceptable, greater than 1200 mg/litre taste (Brvold & Ongerth, 1969). Water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste. Fresh water with TDS < 1000 mg/L is mostly acceptable for consumption (WHO, 2011). The streams recorded the lowest TDS values during the rainy season (34.1mg/l). TDS values were higher during the dry season than the rainy season. It is interesting to note that rainfall seems to have a diluting effect on TDS levels, resulting in lower values during the rainy season. On the other hand, TDS levels tend to be higher during the dry season because of factors such as reduced dilution from rainwater, evaporation, and increased human activities (Izonfuo & Bariweni, 2001). It is also noteworthy that different studies have reported varying TDS levels during different seasons, indicating that various factors may influence the TDS levels in freshwater in different regions (Gadhia *et al.,* 2012; Banu et al., 2018). Nonetheless, it is important to note that the World Health Organization recommends that freshwater with TDS levels below 1000 mg/L is mostly acceptable for consumption.

5.2.2 Chemical contamination in water: Nitrate, fluoride, lead, Mercury, Arsenic.

Chemical contaminants are elements or compounds. Mostly these contaminants originate naturally or man-made. Examples of chemical contaminants include nitrogen, bleach, salts, pesticides, metals, toxins produced by bacteria, and human or animal drugs (kamusoko & Jingura 2017).

Contrary to microbiological contamination, chemical contamination leads to health problems primarily through chronic exposure. But Nitrate is one exception to this rule as short-term exposure can cause methemoglobinemia (WHO, 2011).

The occurrence of chemical contaminants is rare and may results from human contamination of a small area only affecting a few water sources. However, three chemicals have the potential to cause serious health problems and to occur over widespread areas. Chemicals such as arsenic and fluoride, can occur naturally, and nitrate which is applied to large areas of agricultural land as fertilizer. These three contaminants are more often found in groundwater, though surface water can also be impacted. The present study analysed chemical contaminants such as Nitrate, Fluoride, Arsenic, Lead and Mercury (WHO, 2011).

Nitrate (NO_3^-) is naturally occurring ions that are ubiquitous in the environment. It is a product of oxidation of nitrogen as part of the cycle required by all living systems or the production of complex organic molecules, such as enzymes and other proteins (Environment Canada, 2003; IARC, 2010). Nitrate originates from agricultural activities (inorganic fertilizers and manure), wastewater treatment, nitrogenous waste products from humans and discharges from industrial processes and motor vehicles (USEPA, 2006; Keeney & Hatfield, 2008).

Drinking water with high levels of nitrate can cause health effects like Methemoglobinemia or Blue Baby Syndrome. This results from nitrate decreasing the blood's capacity to carry oxygen, especially in infants who receive baby formula mixed with water containing nitrate above 10 mg/L (Charmandari et al., 2001; Ward et al., 2005). High levels of nitrate are also associated with recurrent respiratory infections, thyroid dysfunction, negative reproductive outcomes such as spontaneous abortion and certain cancers including cancer of the stomach or bladder (Ward et al., 2005).

The current study recorded high levels of NO_3^- (79 mg/L) from the Gabne-Obuasi during the dry season. Residents in this community rely on water tanker supply and dug out water. High levels of nitrate in the resident's water could be as a result of fetching water from different sources into one container. Similarly, some studies on nitrate levels conducted in the country, recorded nitrate levels above the WHO reference standard of 50 mg/L (Lartsey et al., 2020; Egbe et al., 2020). Some studies have found high levels of nitrate in water sources as a result of freshwater inflow and terrestrial run-off during the rainy season (Karuppasamy and Perumal, 2000).

Fluoride is an inorganic monatomic anion. it is the simplest anion of fluorine which is represented by the chemical formula F^- (Hundnall et al., 2009). It is a naturally occurring mineral and is released from rocks into the soil, water, and air. Fluoride is found in all natural waters at some concentration. Sea water typically contains about 1mg l^{-1} while rivers and lakes generally exhibit concentrations of less than 0.5 mg l^{-1} (UNICEF, 2011). The concentration of fluoride in water is dependent on the nature of the rocks or fluoride bearing minerals. Levels between 0.7 and 1.2 mg/L in drinking water promote healthy teeth and bone development (Freeze and Lehr, 2009), but excessive exposure to fluoride in drinking-water above 1.5 mg/L can even lead to dental fluorosis and skeletal fluorosis, a bone disease that causes pain, stiffness, and fractures (Fawell and Nieuwenhuijsen, 2003; Smedley et al., 2002).

The highest level of Fluoride was detected in Shia in both survey season (5.50 mg/L) for the rainy season and the dry season (3.80 mg/L). All the boreholes in Shia had high levels of Fluoride above WHO standards. It ranged from 2.0 mg/L to 3.80 mg/L in the dry season and varied between 1.80 mg/L to 5.30 mg/L in the rainy season. The borehole with the highest level of Fluoride was detected in a borehole located in the only basic school in the community. This observation implies that the children in this community are at constant risk. This is a serious problem because fluoride levels exceeding 1.5mg/L can cause significant health problems especially in children. This community has reported some cases of dental fluorosis in children in recent years. The presence of dental fluorosis in recent years suggests that the community members may be consuming higher levels of fluoride than they did in the past. Children under the age of two are more susceptible to the harmful effects of fluoride due to their smaller size and developing bodies. In fact, studies have shown that young children can retain 80-90% of a fluoride dose, compared to 60% in adults (Grandjean, 2019). In addition to dental fluorosis, high levels of fluoride intake in young children have been linked to neurological and developmental issues. Studies have shown that exposure to fluoride during early childhood can affect cognitive development, IQ, and behaviour. Araya et al., (2022) concluded that 15% of the areas in Ghana, mainly in the northeast, have a high probability of fluoride contamination which means that people living in those areas may be ingesting too much fluoride through their drinking water. It is especially concerning that an estimated 240,000 children between the ages of 0 and 9 years are in at-risk areas. Numerous studies have been conducted on fluoride contamination in Ghana (Yidana et al., 2012 Firempong et al., 2013; Zango et al., 2019; Ganyaglo et al., 2019). There is a discrepancy in findings regarding the fluoride levels in drinking water, Cheabu and Ephraim found fluoride levels in drinking water to be in optimal range established by WHO guidelines (Cheabu and Ephraim, 2014).

Arsenic (As) occurs naturally in rocks and soil and dissolve easily into groundwater. There are two forms of arsenic that is inorganic arsenic and organic arsenic (Rosas-Castor et al., 2014). Inorganic arsenic compounds are found in soils, sediments, and groundwater, and it's the most harmful type of arsenic. It is also found in rice, cereal grains, and other foods. Organic arsenic compounds are found mainly in fish and shellfish (Lim et al., 2014). These compounds occur either naturally or as a result of mining, ore smelting, and industrial use of arsenic. Exposure to high levels of inorganic arsenic can lead to skin lesions, skin cancer, bladder cancer, lung cancer, and other health effects. Long-term exposure to lower levels of inorganic arsenic can also cause health problems, including skin discoloration, thickening and discoloration of the skin on the palms and soles of the feet, and skin cancer (Smith et al., 2004; Erickson et al., 2018). In many parts of the world, including Bangladesh, West Bengal, and parts of South America, arsenic contamination of groundwater is widespread, and millions of people are at risk of arsenic-related health problems. In these areas, the primary source of drinking water is often groundwater, which may contain high levels of Arsenic (Shaji et al., 2021). Communities in rural areas which rely on ground water are at risk of Arsenic exposure. In the current study As was detected in some water samples but only 2% was above the WHO standards in both survey seasons. The highest As level was detected in a borehole in Gbane-Obuasi a mining community and this water source was closer to a tilling dam. The use of heavy machinery and chemicals during mining activities can cause the leaching of As from rocks and soil into the water sources. Some studies conducted in mining areas in Ghana, have reported high levels of As in ground water (Smedley et al., 1996; Asante et al., 2007; Affum et al., 2015).

Lead (Pb) is the commonest of the heavy elements, accounting for 13 mg/kg of the earth's crust. Several stable isotopes of lead exist in nature, including, in order of abundance, ^{208}Pb, ^{206}Pb, ^{207}Pb, and ^{204}Pb. Lead is present in tapwater to some extent because of its dissolution from natural sources but primarily from household plumbing systems in which the pipes, solder, fittings, or service connections to homes contain lead. PVC pipes also contain lead compounds that can be leached from them and result in high lead concentrations in drinking-water. The amount of lead dissolved from the plumbing system depends on several factors, including the presence of chloride and dissolved oxygen, pH, temperature, water softness, and standing time of the water, soft, acidic water being the most plumbosolvent (Schock, 1989; Schock 1990). Exposure to high levels of lead can have serious health effects, particularly in children. Lead can accumulate in the body over time and can affect the nervous system, cause developmental delays, and decrease IQ. It can also cause anaemia, high blood pressure, and kidney damage in adults (WHO, 2003). Acute exposure to lead can cause dullness, restlessness, irritability, poor attention span, headaches, muscle tremor, abdominal cramps, kidney damage, hallucinations, and loss of memory (Papanikolaou et al., 2005). Signs of chronic lead toxicity, including tiredness, sleeplessness, irritability, headaches, joint pain, and gastrointestinal symptoms, may appear in adults at blood lead levels of 50–80 µg/dl. After 1–2 years of exposure, muscle weakness, gastrointestinal symptoms, lower scores on psychometric tests, disturbances in mood, and symptoms of peripheral neuropathy were observed in occupationally exposed populations at blood lead levels of 40–60 µg/dl (UAEPA, 2018). The study did not detect lead in any of the samples. Contrary to this work some studies have recorded high levels of lead in some water sources in the country (Obiri-Yeboah 2021; Obeng-Gyasi 2022).

Mercury (Hg) is a metallic element that occurs naturally in the environment. Even though Hg is widely distributed in the environment, industrial activities has significantly increased the levels in the environment. Mercury exists in three states elemental (liquid mercury), organic (methylmercury) and inorganic Hg. Elemental or liquid mercury is the form that is commonly used in thermometers and other measuring devices. When heated, it turns into a vapor that can be harmful if inhaled. Organic mercury, specifically methylmercury, is produced by microorganisms in aquatic environments and can accumulate in fish and seafood consumed by humans (Trasande et al., 2005). Inorganic mercury is found in natural deposits, soil, water, and rocks, and can also be released into the environment through human activities such as mining and industrial processes (IPCS, 1991, 2003). Evidence from the study indicated that Mercury increased during the dry season. Even though the difference was not statistically significant, Hg can accumulate in the environment over time and can be toxic to humans and wildlife (Bhan and Sarkar, 2005; Chen et al., 2012). Therefore, even minor increases in Hg levels can have negative impacts. It is important to continue monitoring Hg levels in water sources and take action to reduce Hg contamination. In addition to the seasonal trend, the study also found that water bodies closer to anthropogenic activities, such as mining and farming, had significantly higher levels of Hg. This is consistent with previous research that has highlighted the role of human activities in Hg pollution of water sources (Cobbina et al., 2015; Obiri-Yeboah et al., 2021).

5.2.3 Microbiological contamination in water: Total Coliform, Fecal Enterococci, E. coli, Salmonella spp., and Shigella spp

Total coliform bacteria are microscopic organisms that originate in the intestinal tract of warm-blooded animals commonly found in the environment, such as soil and vegetation but are generally harmless (MDH, 2001; Liukkonen et al., 2002). Even though these bacteria are not naturally present in drinking, their presence indicates the possibility that pathogenic organisms may be present. Total Coliform has been selected as an indicator of harmful organisms in drinking water. Most Coliform bacteria enter sources of water as a result of run off from areas with high concentrations of animals and humans, runoff from septic tanks and sewage plants, animal farms, woodlands and pastures (Olohan et al., 2002). In the present study, total coliform counts were very high with 80% of the samples having levels higher than WHO standards. The problem of open defecation in the study area exacerbates the problem of water contamination. This is evident from the fact that Total Coliform levels were also found to be high in most of the study sites. Open defecation leads to contamination of water sources with human faeces, which can contain harmful pathogens such as bacteria, viruses, and parasites that cause waterborne diseases like cholera, typhoid fever, and diarrhoea. This study indicate that the water sources are contaminated with faecal matter, which poses a serious risk to public health. The presence of total coliform bacterial indicates that other pathogenic microorganisms like E. coli and Salmonella may also be present in the water. Akrong et al., (2019) reported high levels of Total Coliform in drinking water in communities surrounding Lake Bosomtwe. Other studies have also documented high levels of Total Coliform in drinking water in Ghana (Obiri-Danso et al., 2003).

Faecal Enterococci are frequently used as an indicator of water quality because they are commonly found in the intestinal tract of humans and animals, making their presence in water a clear indication of faecal contamination. Research has shown that exposure to water with high concentrations of Faecal Enterococci can cause a range of diseases, including gastroenteritis, skin infections, and urinary tract infections. (USEPA, 2022). In addition to serving as an indicator of faecal contamination, Faecal Enterococci are also used as a marker for the effectiveness of water treatment processes. Treatment plants can use Faecal Enterococci testing to monitor the efficiency of their wastewater treatment processes and to ensure that their effluent meets established water quality standards. The presence of faecal enterococci in water samples indicates the potential presence of faecal contamination from various sources such as sewage, animal waste, or other sources. During the rainy season, there is increased runoff of rainwater carrying surface contaminants into rivers and other water bodies, thereby increasing the levels of faecal enterococci in the water. This trend has been observed in other studies conducted in the country (Offosu et al., 2014; Yeleliere et al, 2018). Dzodzomenyo et al., (2022) found a significant increase in faecal indicator bacteria (thermotolerant coliforms and *E. coli*) in groundwater during flood season.

Other harmful coliform bacteria, like enterohemorrhagic E. coli (EHEC), can cause severe illnesses such as haemolytic uremic syndrome (HUS) and even death in some cases.
High levels of rainfall can lead to increased levels of bacterial contamination in water due to various factors such as runoff from the land, increased mixing of water, and potential sources of pollution being washed into water bodies. E. coli is one of the common indicators of fecal contamination and its high counts in water samples during the rainy season suggests that the water may not be safe for consumption or for recreational purposes without appropriate treatment or disinfection. Our study, however, found a prevalence of 82% in well water samples during the rainy season and 36% during the dry season. Overall, these studies highlight the importance of regular monitoring and quality control of water sources to ensure safe water access for all. This work is also comparable to that of other researchers. Odonkor & Mahami, (2020) used E. coli as a measurement tool to evaluate the health risks associated with the sources of drinking water in the Dangme West District. Momtaz et al., (2013) examined 448 water samples for E. coli and found 34 (7.58%) samples to be positive for E. coli. Contrary to these studies, Duwiejuah et al. (2013) analysed sachet water samples in the Tamale Metropolis and found no E. coli in them.

These are Gram-negative, non-motile, facultatively anaerobic, non-spore-forming rods and rod-like members of the family Enterobacteriaceae, which grow in the presence or absence of oxygen. The genus is divided into four serogroups with multiple serotypes: A (*S dysenteriae*, 12 serotypes); B (*S flexneri*, 6 serotypes); C (*S boydii*, 18 serotypes); and D (*S sonnei*, 1 serotype) (Wei et al., 2003).

Shigella spp. cause shigellosis, which is characterized by diarrhoea, abdominal cramps, and fever (Niyogi, 2005). The illness is usually self-limiting, but can be severe and life-threatening, especially in young children, the elderly, or individuals with weakened immune systems. The bacteria are transmitted through faecal-oral route, typically by contaminated food or water, or by person-to-person contact. The shigella counts were found to be higher and more variable during the rainy season, with some samples exceeding the WHO standards. However, during the dry season, the organism was not detected in most samples. Overall, the median count of shigella was low in both seasons, but it is important to monitor and control the levels of this pathogen in water to prevent the spread of disease. Recent evidence in literature recorded high levels of Shigella spp. in drinking water sources (Bakobie et al., 2020). This study contrast with findings of a previous study conducted by Dzozomenyo et al., (2022). The study did not detect bacterial pathogens (Shigella spp or Salmonella spp.) in borehole samples in samples from any of the sampling seasons.

Salmonella spp. are members of the Enterobacteriaceae group which resides in the intestinal tract of human beings and warm-blooded animals and are capable of causing disease (Forshell, 2006). They are motile, Gram-negative bacilli that do not ferment lactose, but mostly produce hydrogen sulfide or gas from carbohydrate fermentation. These bacteria are widely distributed in the environment. However, some species or serovars show host specificity. Particularly, S.

Typhi and generally S. Paratyphi are restricted to humans, although livestock can occasionally be a source of S. Paratyphi (Sanderson et al., 2015). These pathogens typically enter water sources through faecal contamination from sewage discharges, livestock and wild animals. Human exposure to these bacteria can result in gastroenteritis, bacteraemia or septicaemia and typhoid fever/enteric fever. Overall, Salmonella was found in a significant portion of the water samples tested, with higher counts recorded during the dry season. However, it should be noted that in most samples, Salmonella was not detected at all, indicating that overall water quality was relatively good. Nonetheless, the presence of Salmonella in water sources highlights the potential health risks to humans exposed to contaminated water. The higher counts during the dry season may be because water sources are reduced and become more stagnant, providing a better environment for bacterial growth This trend is consistent with published literature (Dekker et al., 2015; Akrong etal., 2019; Amuah et al., 2021).

5.2.4 Seasonal Variation of water pollutants during rainy and dry season

Results from the study revealed that almost all sources of water in the area experienced significant deterioration in water quality during both seasons, with rainfall having a stronger negative impact than the dry season. It is important to note that some specific contaminants like total coliform, faecal enterococci, E. coli, and Shigella decreased during the dry season while Salmonella increased during the dry season. These findings are consistent with similar outcomes from recent published literature on water quality which showed that several types of water sources, including boreholes, suffered from greater contamination during the rainy seasons (Kumpel et al., 2017; Toraskar et al., 2022).

The increase in fluoride during the rainy season is concerning as low levels of fluoride in drinking water can have adverse health outcomes, particularly on dental health. There was increase in nitrate during the dry season in Gbane-Obuasi while the other remaining communities had lower nitrate levels during the dry season. The increase in nitrate levels could be attributed to the source of water brought to the community by the water suppliers.

The reduction in total dissolved solids, electrical conductivity and other physicochemical properties during the rainy season could be because of the dilution of water sources with rainwater. This is consistent with the fact that rainwater is typically low in total dissolved solids and other physicochemical as it has not come into contact with the natural environment, whereas other sources of water may have accumulated these contaminants. A lot of published literature has reported on lower levels of TDS, EC, Fluoride and some physicochemical parameters during the rainy season than in the dry season (Gadhia *et al.,* 2012; Ganiyu et al., 2018; Samlafo et al., 2022). In contrast to this, a study conducted by Patel revealed enhanced levels of TDS, EC and other physcochemicals properties during the rainy season (Patel & Parikh, 2013). It also contrasts with findings of previous studies of surface waters which found no significant seasonal differences in faecal indicator bacterial (Vieira et al., 2016; Vieira et al., 2017).

5.2.5 Variations of water pollutants at the main source and households

Hundred (100) paired samples of water sources and the closest available household water storage unit were taken. Disease-risk category distribution was significantly different between the water source and the household supplies for these paired samples, with households having higher disease-risk levels than the main source.

It is concerning to see that some water quality parameters deteriorated significantly in the households compared to the main water source, particularly during the rainy season. This difference in water quality levels could be a result of several factors such as distance to the water source, collection container, and water storage (UNICEF, 2008). Wright et al., (2004) also note the risks of contamination during such bucket transport. They suggested that transportation methods and storage are a concern for water quality in locations where point sources are the primary source and water is not delivered directly to households through pipes. Water in the study area was regularly transported from the original source to the household storage areas using containers. Improper handling and storage of collection and continues dipping of cups by different hands in stored water are some of possible explanation for high levels of contamination at the household.

It is important to address these factors to improve water quality and minimize the potential health risks associated with consuming or using contaminated household water. This study is in coherent with the 2014 Ghana Demographic and Health Survey and the 2018 Multi Indicator Cluster Survey. Their reports indicated high levels of microbial pollutant at the household compared to the main source (Parker et al., 2004; GDHS, 2014; MICS, 2018). Another study conducted in Oforikrom municipality by (Appiah-Effah et al., 2021), concluded that water microbial water quality deteriorates during transportation from the source to the point of consumption due to improper water handling.

It is also noteworthy that microbial contamination was higher at the household level than at the main source. This emphasizes the importance of water treatment and proper storage to reduce potential health risks associated with consuming untreated water.

5.2.6 Water Quality Index

The majority of the water samples from these communities have marginal water quality. Understanding the specific factors contributing to this is crucial to identifying effective solutions that can improve water quality and minimize potential health risks associated with consuming or using contaminated water. It is also interesting to note that the study found that water quality improved during the dry season. This may be attributed to a variety of factors such as reduced runoff and decreased levels of pollutants, which could lead to improved water quality. This is in contrast to Water quality analysis studies conducted in the same study area by (Chegbeleh et al., 2020). He reported the spatial classification of water as “good” to “excellent” for domestic purposes. The good and excellent water quality could be attributed to the fact that their study only analyzed for major ions and trace element. Bacteriological analysis is a crucial component in determining overall water quality for domestic use, as microorganisms present in water can have significant health impacts on humans. It's possible that the water in the study area classified as "good" to "excellent" for domestic use may have contained harmful microorganisms that were not accounted for in the previous study by (Chegbeleh et al., 2020).

5.3 Sanitary inspection of water facilities and human health risk assessment

5.3.1 Combined Sanitary Inspection and Water Quality Analysis

The sanitary hazard index showed that in the rainy season, 64% of the water points analyzed had a very high risk of Total Coliform contamination based on the established threshold by WHO. This means that urgent action is required for areas with 24% and 12% risk levels as these are considered low risk. For the dry season, bacteriological testing revealed that 34% of the sites had counts greater than 100 CFU/100mL 42% had Total Coliform counts between 11 and 100 CFU/100mL and 12% had low risk. The main risk identified from the boreholes was that the majority of the boreholes had their pumps damaged or loose at the point of attachment to the cover slab thus allowing contaminants into the water source. All the boreholes with lose screws had high levels of bacteria contaminants in the water. None of the boreholes had a fence or barrier around them to prevent animals from entering the well area. Most of the wells had pollution sources like sanitation facilities and farms in proximity. At the household level most collection containers used for collecting water were also used for washing and kept at a place that could easily be contaminated and were left uncovered. The median distance between possible sources of contaminants and source of water was 11.58m (14.17m). Several studies have documented prioritization of water sources for rehabilitation or repairs as a major benefit of sanitary inspection and it is the main objective of the SHI (Lloyd & Bartram, 1991; Bacci & Chapman, 2011; Barthiban & Lloyd, 2011).

5.3.2 Chemical Health Risk Assessment

The findings from the chemical health risk assessment highlight the potential health risks associated with the presence of Arsenic, Mercury, and Fluoride in the water samples analyzed during both the rainy and dry seasons. The Hazard Index (HI) values indicated the potential for adverse health effects, with values exceeding the safe limit of less than 1 in a significant portion of the samples.

The kidney is identified as the target organ for these contaminants, suggesting that prolonged exposure to elevated levels of Arsenic, Mercury, and Fluoride in drinking water could pose a significant risk to kidney health. It is concerning to note that 16% of the sample points during the dry season had HI values above the safe limit, indicating a higher potential for adverse health effects.

The liver is a vital organ that plays a crucial role in detoxification and metabolism. It is responsible for filtering toxins and waste products from the bloodstream, breaking down medications and chemicals, and producing bile to aid in digestion. However, when exposed to certain harmful substances like arsenic and nitrate, the liver can be adversely affected.

In the context of water contamination, the presence of arsenic and nitrate in unsafe levels can pose a significant threat to the liver. Arsenic is a highly toxic element that can accumulate in the liver over time, leading to liver damage and potentially increasing the risk of developing liver cancer. Similarly, excessive nitrate levels in the body can be converted into nitrites, which can interfere with the liver's ability to process toxins and disrupt its normal functioning.

The mentioned hazard indices indicate the percentage of water samples that exceed the safe limit for arsenic and nitrate during different seasons. The fact that 10% of the sample's points exceeded the safe limit in the dry season suggests a higher risk of liver damage for those consuming water from these sources. However, the percentage decreased to 2% during the rainy season, indicating a relatively lower risk during that period.

This is coherent with a study by Ebenezer et al., (2021) who concluded on the hazard index of water from Bolgatanga being likely to pose negative health effects on children and adults, but the proportion was relatively small for infants.

Arsenic, a highly toxic element, is known to cause various types of cancer, including lung, bladder, and skin cancers. The fact that a significant proportion of water samples exceeded the acceptable threshold for carcinogenic risk raises concerns about the long-term health consequences for the residents. Chronic exposure to elevated levels of arsenic in drinking water can lead to the accumulation of the element in the body, increasing the risk of developing cancer over time. The disparity between the rainy and dry seasons is also noteworthy. The higher levels of arsenic detected in water during the rainy season could be attributed to various factors such as increased runoff from surrounding areas or changes in groundwater levels. This seasonal variation further emphasizes the need for continuous monitoring and effective management of water sources to ensure the safety of the community.

Though all the water points had Hg contaminates below WHO guidelines, its presence in water is a serious problem because it is a persistent and lipophilic and can bioaccumulate in the human body (Tanabe *et al*., 2000; Kishimba, 2004). Therefore, its presence in water is not good for human consumption.

5.3.3 Concentration of pathogen and indicator organisms

The drinking water sources from boreholes and streams were the sources of microbial contaminants uncovered. Pathogen hazards of the borehole well and river revealed microbial contaminations, which may be triggered by unsanitary and improper maintenance of the water sources (Tan et al., 2016). Poor sanitation and hygiene coupled with unsafe handling and storage of water were observed in the majority of the households which might have led to higher levels of microbial contaminants recorded at the household level. The median concentration of E. coli recorded in the household was 54.5 CFU/100mL, 19 CFU/100mL during the rainy and dry season respectively. At the main source, the median E. coli recorded was 35 CFU/100mL and 16 CFU/100mL for the rainy and dry seasons respectively. There was no detectable level of Shigella spp., at the main source during the dry season yet during the same season, the median level of shigella spp., recorded at the household was 4 CFU/100mL.

5.3.4 Risk of Infection

Seasonal variation of probability of infection from E. coli, Salmonella spp., and Shigella spp., were determine for all sources of water from the four communities using their pathogenetic strain. The highest risk of infection due shigella was recorded from the stream during the rainy season (3.58 x10^{-2}). The study observed a change in risk as a result of rainfall events that increases runoff to the stream and therefore increases the concentration of E. coli, Salmonella spp., and Shigella spp., in the stream. The calculated levels of disease burden associated with E. coli, Salmonella and Shigella from the borehole, stream and reservoir were compared to WHO reference level of risk (10^{-6} DALY) (WHO, 2012). The disease burden from the stream associated with Salmonella, Shigella and E. coli (8.74 x10^{-4}, 2.84 x10^{-4}, 5.02. x10^{-5}) respectively were higher than the risk posed by the water from the reservoir. Disease burden from the borehole associated with Salmonella (1.24 x10^{-2}), Shigella (2.04 x10^{-2}) and E. coli, (9.79 x10^{-5}) were all higher than the WHO reference level of tolerable risk. This is study's outcome is coherent with other previous studies conducted in the country which recorded high disease burden at the point of consumption of drinking water (Machdar et al., 2013; Yeboah et al., 2022).

5.4 Land use and land cover change, surface modeling of water pollutants and estimated population at risk.

5.4.1 Coverage of land use/land cover types in 2020 and 2021

Spectral retrieved land use land cover indices integrated with laboratory analysis indicated available resources and anthropogenic activities. This facilitated the spatial assessment of probable sources of pollution (Elbeith & Elzeiny, 2018). Land use and land cover can significantly alter river water. The conversion of natural vegetation to agriculture, urbanization, and aquaculture can contribute to increased nutrient pollution, leading to negative impacts on water quality. This study evaluated the LULC of the study area and the physical, biological and chemical characteristic of water in the area. Critical examination of these two-land use/land cover maps revealed that water coverage decreased during the dry season, a 37% decrease in water during the dry season significantly impacted households' access to improved water sources and the amount of time residents spend to get water. Most of the water area has been reduced and converted into bare land. The majority of the surface water sources have vegetation around them.

5.4.2 Interpolation

The final WQI and Fluoride maps provided a great insight into seasonal impacts on the overall water quality, as water quality gets better during the dry season. An increase in water quality was evident when comparing the rainy season to the dry season. As previously mentioned before a significant difference in the average values means that the quality of water was noticeably higher in the rainy season. During the rainy season, the north-eastern part of the district showed most of the sampled points had marginal water quality with a few points representing fair quality. The north-western part of the district also showed that a larger part of the district exhibited marginal water quality with small portions showing fair to excellent water quality. Based on the prediction models computed for water quality in the communities, predictions made during the dry season were better that the rainy season. A significant increase in water quality in the dry season is evident with reference to the surface interpolation, as the north-eastern part to the southern part of the map show fair water quality with a little portion showing marginal quality. The west part indicated fair water quality with the north-west showing marginal water quality. This contrasts with Chegbeleh et al., (2020) who concluded on the quality of water in Talensi as groundwater for domestic usage deteriorates as one moves towards the north of the district, whereas waters in the east and west present the best quality. Fluoride levels were very high in the beginning of the study (rainy season) and the north-western part of the study area had levels above WHO standards. The dry season predicted model of fluoride indicated a strong linear relationship between its predictions and true values than the wet season. The other parts of the study area had levels within the WHO reference standard. The results from this study are in coherent with a study by Araya et al., (2022). Their study revealed that the northeastern part of the country, has the highest exposure to fluoride. The surface interpolation hazard map of the study further revealed that north-western part of Talensi had high levels of Fluoride with an estimated of 1950 people being exposed in the study area during the dry season and 2012 being exposed during the rainy season.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.0 Introduction

This chapter presents the summary and conclusions of the study findings outlined according to the study objectives. In light of the objectives and findings, specific recommendations have been made, as well as highlights on contribution to current knowledge and making suggestions for further studies.

6.1 Conclusions

The study found that the proportion of households with access to improved drinking water were higher in the rainy season than the dry season. This is because during the rainy season, households may have access to rainwater harvesting systems or temporary improvements in local water tables, making water more available and cleaner. The study revealed that socioeconomic status has a critical role in determining access to improved water, particularly during periods of scarcity such as the dry season.

According to the sanitary inspection guidelines provided by UNICEF and WHO, the majority of the inspected boreholes in the district were not maintained optimally, and the household practices were not in accordance with the WHO guidelines.

The median total coliform, E. coli, Shigella spp., and Salmonella spp., of the water samples were found to be significantly different between the intake and point-of-use water sources, respectively, as well as rainy and dry seasons.

Base on the cancer risk assessment, long-term consumption of water from these areas poses an unacceptable cancer risk according to international standards.

The non-carcinogenic risk revealed concerning levels of non-carcinogenic health risk from exposure to various contaminants, especially during the dry season, the study highlights the vulnerability of critical organs such as the liver and kidneys**.** Also, the study found that the drinking water sources in the area had poor microbiological quality, with the presence of coliforms, E. coli, Salmonella, and Shigella. The spatial modelling of water quality and Fluoride helped to identify areas of poor and good water quality as well as areas with high levels of fluoride contamination as well as the population at risk.

Most of the north-western part of the district exhibited marginal water quality with small portions showing fair to excellent water quality.

6.2 Recommendations

The findings of this study have a crucial contribution and implication for prompt action from a public health perspective in the district. This part of the country has the highest proportion of rural population and therefore the highest dependency on groundwater. Sustainable interventions should be prioritised to ensure the availability of clean and safe drinking water for all. This will not only improve the health outcomes of the community but also enhance the overall quality of life. Therefore, the following suggestions are being made to the concerned bodies accordingly.

Policy: Integrated Water Resources Management

Integrated water resources management should aim at putting in place mechanisms to increase improved water access, such as piped water systems, wells, mechanized boreholes, small-town systems, and protected springs, they should provide communities in semi-arid rural areas with reliable and safe water supply, especially the during dry season. Periodic water quality analysis should be conducted to ensure safe water supply.

National Environmental Sanitation Policy:

The National Environmental Sanitation Policy should strengthen community-led total sanitation programmes and strategies to reduce open defecation.

Public Health Practice: The District Health Directorate under the auspices of the District Assembly can launch education and outreach campaigns to raise awareness about water issues at the household level, such as conservation and hygiene. Even if the water supply is of high quality at the source, it can become contaminated due to poor handling and storage. They can also educate communities about how to store and purify water at the household level to prevent contamination and waterborne diseases.

Local Government

Local governments can play a critical role in planning, funding, and implementing water infrastructure projects. They can work with community leaders, water utilities, and other stakeholders to identify areas that lack safe water and design projects to expand access.

District Assembly

- Increase access to improved water sources: The Talensi District Assembly should prioritize efforts to increase access to improved water sources. This may involve expanding the coverage of piped water systems, drilling more boreholes, and rehabilitating existing ones. The district office can regulate water utilities and ensure that they meet specific standards for water quality and safety. They can also enforce rules that prevent pollution, leakages, or other threats to the local water supply.

- Target areas of high pollution: The Talensi District Assembly should prioritize efforts to reduce water pollution in areas with high levels of contamination. This may include working with mining companies to reduce contamination from mining activities, promoting more sustainable agricultural practices to reduce runoff, and increasing public awareness of the risks of water pollution.

- The district assembly in collaboration with the Ministry of Sanitation and Water Resources, should rehabilitate broken water supply systems. One route contaminant get into water is when the pump is damaged or loose at the point of attachment thus periodic water facility appraisal should be conducted in order to identify broken water facilities.

6.3 Limitations and strengths of study

Limitations

a. Limited scope of water quality parameters analysis.

b. The research did not consider the vulnerability of different population groups particularly immune compromised patients like HIV/AIDS and sickle cell patients in the microbial qualitative risk assessment.

c. Lead was not detected in any of the samples, it could be due to the detection limit of the instrument being too high.

Strengths

- Mixed methods application: This study used a mix of quantitative and qualitative methods and sequential explanatory approach to assess household improved water access and associated factors.

- The application of different models: the study applied different models to boost findings transferability.
- This study represents a comprehensive assessment of improved water access and water quality assessment.

6.4 Future research direction

- This study did not analyze virus and other harmful bacterial in the water samples. Therefore, future research could investigate virus and other harmful bacteriological contaminants like rotavirus, Clostridium perfringens etc.

- This study did not include susceptible groups like HIV patients and sickle cell patients who are immune compromised in the QMRA. Future studies can include these groups in the risk analysis.
- Other future studies should use other analytical instruments with lower detection to measure lead in water.

6.5 Contribution to knowledge and literature

- This study presents the first instance where a fluoride hazard map has been specifically generated for a community.

- The study found that access to improved water sources in Talensi District was adequate especially during the rainy season yet most of the improved sources were contaminated with either chemical or bacteria. This creates a significant risk of waterborne diseases, particularly during the rainy season. The study found that water quality in Talensi District varied significantly across seasons.

- The study found that the geospatial distribution of water pollutants in Talensi District was highly variable, with some areas having high levels of pollution while others had lower levels. Areas with high levels of pollution tended to be areas with higher population densities and closer to sources of contamination such as mining activities and agricultural land use.

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APPENDICES

Appendix A: INTERVIEW GUIDE (FACE TO FACE)

Part 1- General Information

1. Sex of respondent
   Male [ ] Female [ ]

2. Age of respondent

3. Relationship of the respondent to the household head
   [ ] Household Head [ ] Spouse [ ] Father or Mother [ ]Child [ ] Brother or Sister [ ] Others (Specify)

4. Sex of household head
   Male [ ] Female [ ]

5. Age of household head

6. Educational level of the household head?

   None [ ] Primary [ ]

   Middle/JHS [ ] Secondary or above [ ]

7. Occupation of household head
   Employed [ ] Unemployed [ ] Economically not active [ ]

8. Marital status household head:

   [ ] Single [ ] Married [ ] Widowed [ ] Separated

9. Religion of household head:

   [ ] Christianity [ ] Islam [ ] Traditionalist

10. To what ethnic group does the head of this household belong?

    a. Akan
    b. Ga/Dangme
    c. Ewe
    d. Guan
    e. Gruma
    f. Mole Dagbani
    g. Grusi
    h. Mande

i. Non-Ghanaian
j. Other ethnic group (Specify)

11. Location of household
    a. [ ] Urban b. [ ]. Rural
12. Do they mine in this community

    a. Yes
    b. No
    c. Don't know

PART 2 - ACCESS TO WATER

13. What is the main source of drinking water for members of your household

    during the dry season (single response)?

    a. Pipe-borne inside dwelling
    b. Pipe-borne outside dwelling but on compound
    c. Pipe-borne from neighbouring house
    d. Public tap/standpipe
    e. Borehole/Pump/Tube Well
    f. Protected well
    g. Harvested Rain water
    h. Protected spring
    i. Bottled Water
    j. Sachet Water
    k. Tanker supply/Vendor Provided
    l. Unprotected well
    m. Unprotected spring
    n. River /Stream
    o. Dug out/pond/Lake/Dam/Canal
    p. Other (Specify)

14. What is the main source of water used by your household for other purposes, such as cooking and hand washing purposes during the dry season (single response)??
    a. Pipe-borne inside dwelling
    b. Pipe-borne outside dwelling but on compound
    c. Pipe-borne from neighbouring house
    d. Public tap/standpipe
    e. Borehole/Pump/Tube Well
    f. Protected well
    g. Harvested Rainwater
    h. Protected spring
    i. Bottled Water
    j. Sachet Water
    k. Tanker supply/Vendor Provided
    l. Unprotected well
    m. Unprotected spring
    n. River /Stream

o. Dug out/pond/Lake/Dam/Canal
p. Other (Specify)

15. Where is the water source located?

a. In own dwelling
b. In own yard/plot
c. Elsewhere

16. How long does it take to go there, get water, and come back?

a. on premises
b. Number of minutes (Specify)
c. Don’t know

17. How far is the water source from your house?

a. Less than 100m
b. Between 100m-200m
c. More than 200m

18. Who usually goes to this source to fetch water for your household?

Note: Select the individual primarily responsible for water collection

a. Adult woman (>15 years)
b. Adult man (>15 years)
c. Girl (<15 years
d. Boy (<15 years)

19. Do you pay for water?
a. Yes
b. No

If the answer is “No” then move to question 20.

20. How much do you pay for one gallon of water?

21. What is the main source of drinking water for households during <u>the rainy season</u>?
a. Pipe-borne inside dwelling
b. Pipe-borne outside dwelling but on compound
c. Pipe-borne from neighbouring house
d. Public tap/standpipe
e. Borehole/Pump/Tube Well
f. Protected well
g. Harvested Rain water
h. Protected spring
i. Bottled Water
j. Sachet Water

k. Tanker supply/Vendor Provided
l. Unprotected well
m. Unprotected spring
n. River /Stream
o. Dug out/pond/Lake/Dam/Canal
p. Other (Specify)

22. What is the main source of water used by your household for other purposes, such as cooking and hand washing purposes during the rainy season?
    a. Pipe-borne inside dwelling
    b. Pipe-borne outside dwelling but on compound
    c. Pipe-borne from neighbouring house
    d. Public tap/standpipe
    e. Borehole/Pump/Tube Well
    f. Protected well
    g. Harvested Rain water
    h. Protected spring
    i. Bottled Water
    j. Sachet Water
    k. Tanker supply/Vendor Provided
    l. Unprotected well
    m. Unprotected spring
    n. River /Stream
    o. Dug out/pond/Lake/Dam/Canal
    p. Other (Specify)

23. Where is the water source located?

    a. In own dwelling
    b. In own yard/plot
    c. Elsewhere

24. How long does it take to go there, get water, and come back?

    a. On premises
    b. Number of minutes
    c. Don't know

25. How far is the water source from your house?

    d. Less than 100m
    e. Between 100m-200m
    f. More than 200m

26. Who usually goes to this source to fetch water for your household?

    Note: Select the individual primarily responsible for water collection

    a. Adult woman (>15 years)

b. Adult man (>15 years)
c. Girl (<15 years
d. Boy (<15 years)

27. Do you pay for water?

a. Yes
b. No

If the answer is "No" then move to question 28.

28. How much do you pay for one gallon of water?

29. In the last month, has there been any time when your household did not have enough drinking water when needed?

a. Yes, at least once
b. No, always sufficient
c. Don't know

30. Do you store water in containers?

a. Yes
b. No

If the answer is "No" then move to question 32.

31. What type of containers do you store water in? Can you show me?

Note: Observe whether containers are covered or uncovered

a. Water stored in covered containers
b. Water stored in uncovered containers
c. Unable to observe

32. Do you treat your water in any way to make it safer to drink?

c. Yes
d. No

If the answer is "No" then move to question 33.

33. What do you usually do to the water to make it safer to drink?

a. Boil
b. Add bleach / chlorine
c. Strain it through a cloth
d. Use water filter (ceramic, sand, composite, reverse osmosis, etc.)
e. Solar disinfection

f. Let it stand and settle
g. Add camphor/naphthalene
h. Don't know
i. Other (specify)

34. Is the water supplied from your main source usually acceptable?

a. Yes
b. No

If the answer is "Yes" then move to question 36.

35. If unacceptable, select the main reason.

a. Unacceptable taste
b. Unacceptable colour
c. Unacceptable smell
d. Contains materials
e. Other (specify)
f. Don't know

36. Which of the following sources of water are available in your neighborhood (multiple response)?

a. Pipe-borne inside dwelling
b. Pipe-borne outside dwelling but on compound
c. Pipe-borne from neighbouring house
d. Public tap/standpipe
e. Borehole/Pump/Tube Well
f. Protected well
g. Harvested Rain water
h. Protected spring
i. Bottled Water
j. Sachet Water
k. Tanker supply/Vendor Provided
l. Unprotected well
m. Unprotected spring
n. River /Stream
o. Dug out/pond/Lake/Dam/Canal
p. Other (Specify)

Part -3 Seasonality

37. How many rainfall seasons do you have in a year?

38. Which months do you get rainfall?

39. How long does the wet or rainy season in this district last?

   a. 1 month
   b. 2 months
   c. 3 months
   d. 4 months
   e. 5 months and above

40. Does the rainy season affect your source of water?

   a. Yes
   b. No

If yes then move to question 42

41. How does it affect your source of water?

   a. Water source gets submerged
   b. Damage water source
   c. Contaminate water source

42. Which months do you get drought?

43. How long does the dry season in this district last?

   a. 1 month
   b. 2 months
   c. 3 months
   d. 4 months
   e. 5 months and above

Do you experience water shortage during dry season?

   a. Yes
   b. No

44. Average time period of water shortage

   a. <1- day
   b. 1-day
   c. 2-3 days
   d. Not applicable
   e. More than a week
   f. Do not know

45. Which period of the year do you face maximum water shortage?

   a. January-March
   b. April-June
   c. July-September
   d. None
   e. Always

46. What is the problem you usually face with water supply?

   a. Irregular
   b. Unclean
   c. Too far
   d. Dirty water
   e. Saline
   f. Smell
   g. Bad taste
   h. None

47. When was the last time the water facility broke down?
   a. during last week
   b. One month ago
   c. Three months ago
   d. More than 3 month ago
   e. Never broke down

48. Last time the facility water broke down, how long did it take to have it fixed and working again?
   a. Immediately/Few days
   b. One week
   c. During the same month
   d. More than one month
   e. Not fixed yet

49. The last time the water facility broke down, how did you get water?

Part 5 - SANITATION

50. What kind of toilet facility do members of your household usually use?

   a. Flush/pour flush to:
      I. Piped sewer system,
      II. Septic tank,
      III. Pit latrine,
      IV. Elsewhere,
      V. Unknown place/not sure

   b. Ventilated improved pit latrine (VIP)

c. Pit latrine with slab
d. Pit latrine without slab/open pit
e. Composting toilet
f. Bucket
g. Bucket Hanging toilet/hanging latrine
h. No facilities or bush or field,
i. Other (specify)

51. Do you share this toilet facility with other households?
a. Yes [ ] b. No [ ]

52. Do you share this facility with another household?

a. Yes, other households only
b. Yes, public
c. No

53. How many households use this toilet facility?

54. Where is this toilet facility located?

a. In own dwelling
b. In own yard plot
c. Elsewhere

55. The last time the youngest member of your family passed stools, where did you dispose of the stools?
a. Child used toilet/latrine
b. Put/rinsed into toilet or latrine
c. Put/rinse into drain or ditch
d. Throw into garbage
e. Buried
f. Left in the open
g. Other (specify)
h. DK

PART 6- HOUSEHOLD CHARACTERISTICS

56.	Does your household have:	YES	NO
	Electricity?		
	A wall clock?		
	A radio?		
	A black/white television?		

A color television?
A mobile telephone?
A land-line telephone?
A refrigerator?
A freezer?
Electric generator/Invertor(s)?
Washing machine?
Computer?
Digital photo-camera?
Non-digital photo-camera?
Video deck?
DVD/VCD?
Sewing machine?
Bed?
Table?
Cabinet/Cupboard?
Internet access?

57. What type of fuel does your household mainly use for cooking?

a. Electricity
b. LPG/Natural Gas
c. Biogas
d. Kerosene
e. Coal, Lignite
f. Charcoal
g. Firewood,
h. Straw/shrubs/grass
i. Agricultural crop
j. Animal dung
k. No food cooked in household
l. Other (Specify)

58. What type of oil does your household mainly use for cooking?

a. Red Palm oil
b. Yellow palm oil
c. Frytol/fortified vegetable
d. Oil
e. Other vegetable oil
f. Shea butter
g. Other (Specify)
h. Don't know

59. Is the cooking usually done in the house, in a separate building, or outdoors?

a. In the house
b. In a separate building
c. Outdoors
d. Other 6 (specify)

60. Do you have a separate room which is used as a kitchen?

a. Yes
b. No

61. Main material of the floor in the dwelling. Record observation.

Natural floor
a. Earth/sand dung

Rudimentary floor
b. Wood planks palm/bamboo

Finished floor
Parquet or polished
c. Wood
d. Vinyl or asphalt strips

Ceramic/Marble/Porcelain
e. Cement

Woolen Carpet/Synthetic
f. Carpet
g. Linoleum/rubber carpet
h. Other (Specify)

62. Main material of the roof in the dwelling record observation.

Natural roofing
a. No roof
b. Thatch/palm leaf/sod

Rudimentary roofing
c. Rustic mat
d. palm/bamboo
e. wood planks
f. cardboard

Finished roofing
g. Metal
h. Wood
i. Calamine/cement fiber
j. Ceramic tiles/brick tiles

k. Cement
l. Roofing shingles
m. Asbestos/slate
n. Roofing sheets
o. Other (Specify)

63. Main material of the exterior walls. Record observation.

Natural walls

a. No walls
b. Cane/palm/trunks
c. Dirt/Land Crete

Rudimentary walls

d. bamboo with mud
e. stone with mud
f. uncovered adobe
g. plywood
h. Cardboard
i. Reused wood

Finished walls

j. Cement
k. Stone with lime/cement
l. bricks
m. Cement blocks
n. Covered adobe
o. Wood planks/shingles
p. Other (Specify)

64. How many rooms in this household are used for sleeping?

65. Does any member of this household own?	YES	NO
A wristwatch?		
A bicycle?		
A motorcycle or motor scooter?		
An animal-drawn cart?		
A car or truck?		
A boat with a motor?		
A boat without a motor?		

66. Does any member of this household own any agricultural land?

a. Yes

b. No

67. How many hectares or acres or plots of agricultural land do members of this household own?
(If 99.5 or more acres, record in hectares. 100 acres= 1 hectare)

68. Does this household own any livestock, herds, other farm animals, or poultry?

a. Yes
b. No

69. How many of the following animals does this household own?

Animals	Number
Cattle?	
Milk cows or bulls?	
Horses, donkeys, or mules?	
Goats?	
Pigs?	
Rabbits?	
Grasscutter?	
Sheep?	
Chickens?	
Other poultry?	
Other?	

70. Does any member of this household have a bank account?

a. Yes

b. No

Appendix B: FOCUS GROUP DISCUSSION (FDG) FOR COMMUNITY MEMBERS

Date: ___________________________.
Translator/recorder name: ___________________________.
Note taker: ___________________________.
Location: ___________________________.
Start time: ___________________________.
End time: ___________________________.
Number of male participants: ___________________________.
Number of female participants: ___________________________.
Pseudonyms/IDs for participants and seating chart ___________________________.

(Read project objective, read the consent to participants and then administer consent and then proceed with interview….)

Readout: Do I have your permission to proceed with the interview? Can I record it/take notes?

1. What are the water needs (drinking, washing, bathing, cooking e.t.c.) of households in this community?
2. What is/are the water source(s) that supplies most of the households' water needs?
   a. improved water sources/pipe-borne water/borehole water e.t.c.
   b. unimproved water sources/rivers/dams/wells e.t..c.
3. How do households access improved water sources?
   a. direct connection to the home or a public water facility within 200 meters of the home
   b. indirect connection to the home or a public facility beyond 200 meters of the home
4. How easy or difficult is it for households to access improved water sources?
   Probe:
   a. pipe-borne water
   b. borehole water e.t.c.
   c. other treated/improved water sources

5. How is water treatment done among households?
   Probe:
   a. Is water treatment done within or outside the household?
   b. What type of treatment method/technology is utilized?

6. What type of toilet facility do members of this community usually use?
   Probes:

   a. availability and utilization of latrine in households
   b. availability and utilization of community KVIP
   c. the practice of open defecation.

7. What are the problems you usually face with water supply?
8. How long/frequent do you experience these challenges?
9. What are some potential causes of a water service/supply interruption? and
10. What important changes have occurred regarding water supply in your community?

    Probe:
    a. Positive changes
    b. Negative changes

11. Who/what has been responsible for the change(s) you indicated?

12. Since the onset of the change in water supply (mention the negative change), what measures have community members put in place to enhance your access to improved water sources?

    Probe:
    a. Key community stakeholders involved.
    b. Specific activities/measures
    c. Mobilization of resources for action
    d. The outcome of the action(s)

13. What changes have you observed in the climate over the past 10 years?

    Probes:
    a. Any changes in the intensity/duration of the rainfall?
    b. Has the duration of the dry season changed?
    c. Is the temperature getting warmer or colder over the past 10 years?

14. How has climate change over the past 10 years affected water sources or facilities in this community?

    Probe:

    a. Flooding and contamination of water sources
    b. Drying up of water bodies
    c. Breakdown of water facilities
    d. Effect of climate change on the current design and construction of water supply infrastructure
    e. Water shortage/insecurity e.t.c.
15. What are some of the adaptation measures you put in place to mitigate the effect of climate change on water sources and water facilities?
16. What capacities (*knowledge, skill, equipment, strategies*) does the community have in adopting these strategies (mention the strategies after the other)
17. What capacities (*knowledge, skill, equipment, strategies*) do the community need in adopting these strategies (mention the strategies after the other)?
18. Any recommendations and final words about the effect of climate change on water sources in this community?

Appendix C: INTERVIEW GUIDE (KEY INFORMANT)

SECTION A: Respondent background and organization

1. What is the mandate (purpose) of your organization? Which aspect of the mandate (purpose) is linked with access to improve water resource or climate change?

The next set of questions is about your recall of past events, back till the past 10 years. If you feel unable to remember any events or situation, kindly let me know.

SECTION B: Household water and sanitation access

2. What are the water needs (drinking, washing, bathing, cooking e.t.c.) of households in this community/district?
   - c. What is/are the water source(s) that supplies most of the households' water needs?
     Probe:
     - a. improved water sources/pipe-borne water/borehole water e.t.c.
     - **b.** unimproved water sources/rivers/dams/wells e.t.c.
   - d. How do households access improved water sources?
     Probe:
     - a. direct connection to the home or a public water facility within 200 meters of the home
     - b. indirect connection to the home or a public facility beyond 200 meters of the home
   - e. How is water treatment done among households?
     Probe:
     - a. Is water treatment done within or outside the household?
     - b. What type of treatment method/technology is utilized?
   - f. What type of toilet facility do members of this community/district usually use?
     Probes:
     - a. availability and utilization of latrine in households
     - b. availability and utilization of community KVIP
     - c. the practice of open defecation.

SECTION C: Challenges and facilitators to household water access

- g. What are the determinants of households' access to water sources?
- h. How easy or difficult is it for households to access these improved water sources?
  Probe:
  - a. pipe-borne water
  - b. borehole water e.t.c.
  - c. other treated/improved water sources
- i. How long/frequent and in which seasons do they experience these challenges?
- j. What are some potential causes of water service/supply interruption from institutions point of operation?

k. What important changes have occurred regarding water supply in your community?
Probe:
   a. Positive changes
   b. Negative changes

l. Who/what has been responsible for the change(s) you indicated?

SECTION D: Climate change and effect on water access

m. What changes have you observed in the climate over the past 10 years?
Probes:
   a. Any changes in the intensity/duration of the rainfall?
   b. Has the duration of the dry season changed?
   c. Is the temperature getting warmer or colder over the past 10 years?
   d.

n. How has climate change over the past 10 years affected water sources or facilities in this community/district?

Probe:

   a. Flooding and contamination of water sources
   b. Drying up of water bodies
   c. Breakdown of water facilities
   d. Effect of climate change on the current design and construction of water supply infrastructure
   e. Water shortage/insecurity e.t.c.

SECTION E: Commitment to improve water access

o. What is the level of priority given to communities' access to improved drinking water resources? In your sector (e.g. Health, WASH, WSU)

p. What measures have your institution put in place to enhance communities' access to improved water sources?

Probe:
   a. Specific measures to address water shortage and water treatment over the past 10 years.
   b. Spearheaded by which stakeholder(s)
   c. How mobilization of resources for action was done
   d. The outcome of the action(s)

q. What are the challenges that prevent your institution from assisting communities with problems with access to improved water sources?
Probe:
a. Capacity and resource gaps (*training, institutional and community-wide resources needed to act)*
r. What do your institution want government, cooperate social workers and NGOs to help your institution in addressing challenges associated with water shortage and treatment?

s. Any recommendations and final words about the effect of climate change on water sources in this community?

Thank you for participating in the interview!!!

Appendix D: WHO Sanitary Inspection Form for Dug well with a pump

Sanitary Inspection Form (Draft: 1 May 2020) **DRINKING-WATER**

Dug well with a hand pump

1. GENERAL INFORMATION

A. Well location and specification

(Record information on the well location and specification. Add "N/A" where information is not applicable.)

Village /town	Community	District

Additional location information: (If using coordinates, state the type and unit e.g. national grid reference coordinates; GPS coordinates.)	

Year of well construction	**Well depth** (and units)	**Approximate number of households served by this water supply**: (Circle one of the options below.)					
		1-5	**6-10**	**11-15**	**16-20**	**21-25**	**26-30**

Is the well located in a flood zone?	Circle one of the options below			If Yes, details (e.g., typical flood frequency, duration, severity):
	unknown	**No**	**Yes**	

B. System functionality

(Circle Yes or No to indicate whether water is currently available from the well. If No, provide details (e.g. faulty or missing component, no/limited water available etc.) and skip to Section II. Record key remedial actions in Section III that are needed to ensure the well can provide water.)

Is water currently available from the well?		If No, details (and skip to Section II):
Yes	No	

C. Weather conditions during the 48 hours prior to inspection

(Indicate the predominant temperature and precipitation conditions during the 48 hours prior to inspection by placing a circle around the options below. Where conditions have been changeable, more than one option may be circled. Additional information may be recorded in Section III.)

Temperature	<0$_o$ Celsius	0-15° Celsius	15-30° Celsius	>30° Celsius
Precipitation	Snow	Heavy rain	Rain	Dry

D. Water sample information

(Use the table below to record details of any water sample taken during the inspection. Include information for any parameters tested. Add "N/A" where information is not applicable. Additional parameters may be recorded in Section III.)

Sample taken?		Sampling location	Sample no. /code	Other sample information	
No	Yes				
Parameter tested		E. coli			

Result and units				

E. Water treatment prior to abstraction/collection

(Answer the question by ticking (3) the appropriate box and providing further information, where applicable.)

☐ No treatment applied at the well

☐ Chlorine applied directly to the well. If so, describe (e.g. chlorine dose, frequency):

☐ Other. Describe (e.g. method, frequency):

Notes:

1. If there are more dug well sources in your community, or if other water sources are used by the community (e.g. springs, boreholes), carry out individual sanitary inspections for these sources as well using the relevant sanitary inspection forms.
2. If users store water in the household, also carry out sanitary inspections using the form “Household practices”.

Sanitary Inspection Form

II. Sanitary inspection

IMPORTANT: Read the following notes before undertaking the sanitary inspection

1. Answer the questions by ticking (3) the appropriate box. For guidance, refer to the numbered risk factors in the illustration below, which are linked to each question on the next page. Note: these are typical risk factors; consider what additional risk factors may be relevant in your local context. Refer also to the Technical Fact Sheet for information on the individual components of the dug well.

2. If there is no risk present, or a question does not apply to the well being inspected, tick the NO box.

3. If a risk is present, tick the YES box. For important situations that require attention, record the actions to be taken in the column provided. These notes can be used to develop a detailed improvement plan, outlining what will be done, by whom, by when and what resources are required. For guidance, refer to the Management Advice Sheet. Where possible, corrective actions should focus on addressing the most serious risks first. Consider low/no cost improvements that can be made immediately.

Sanitary Inspection Form DRINKING-WATER

Sanitary inspection questions	NO	YES (RISK)	What action is needed?

1	**Is the pump damaged or loose at the point of attachment to the cover slab so that contaminants could enter the well?** A damaged or severely corroded pump, or a loose pump that is not securely attached to the cover slab, may allow contaminants to enter the well (e.g. contaminated surface water).			
2	**Is the cover slab absent or inadequate to prevent contaminants entering the well?** The absence of a cover slab, or the presence of a poorly maintained cover slab (e.g. damaged, eroded or with deep cracks), may allow contaminants to enter the well.			
3	**If there is an inspection port, is the lid missing or inadequate to prevent contaminants from entering the well?** A missing, unsealed or unlocked inspection port lid provides a potential route of entry for contaminants to the well (e.g. via contaminated surface water, animals or vandalism).			
4	**Are there any visible deficiencies at any point in the well wall?** Any inadequately sealed points (e.g. gaps, deep cracks, faults) in the aboveground (i.e. headwall) or belowground well wall may result in contaminants entering the well. (Note – if there is no inspection port and a belowground visual inspection of the well is not possible, record this in Section III.)			
5	**Is the apron around the well absent or inadequate to prevent contaminants from entering the well?** A missing apron, or any gaps, deep cracks or faults in an existing apron may allow contaminants to enter the well. For adequate protection, the apron should be at least 1 metera wide all around the headwall, sloping down towards a collar to catch and divert water to a drainage channel			
6	**Is the drainage inadequate, which may result in stagnant water in the well area?** An absent, damaged or blocked drainage channel, and/or the absence of a downward slope for water to drain away from the well, could result in ponding and stagnated water contaminating the well area.			
7	**Is the fencing or barrier around the well absent or inadequate to prevent animals entering the well area?** If the fencing or barrier around the well is absent, broken or poorly constructed, animals could damage or contaminate the well area.			
8	**Is there sanitation infrastructure within 15 meters of the well?** Sanitation infrastructure (e.g. a latrine pit, septic tank or sewer line) close to groundwater supplies may affect water quality (e.g. by seepage or overflow and subsequent infiltration). You may need to visually check structures to see if they are sanitation-related, in addition to asking residents.			
9	**Is there sanitation infrastructure on higher ground within 30 meters of the well?** Groundwater may flow towards the well from the direction of the sanitation infrastructure. Pollution on higher ground poses a risk, especially in the wet season, as faecal material and other pollutants may flow into the well.			
10	**Can signs of other sources of pollution be seen within 15 meters of the well (e.g. animals, rubbish, human settlement, open defecation, fuel storage)?** Animal or human faeces on the ground close to the well constitute a serious risk to water quality. Presence of other waste (e.g. household, agricultural, industrial etc.) also constitutes a risk to water quality			
11	**Is there any point of entry to the aquifer that is unprotected? within 100 metersa of the well?** Any point of entry to the aquifer that is unprotected (e.g. uncapped/open well or borehole) is a direct pathway for contaminants to enter the well.			

Total number of risks identified: .... /11

Total risk score (# of y) ……………. out of 11

Risk Score 0-3 = low; 4-5=medium; 6-7 = high; 8-10 =very high

III ADDITIONAL DETAILS – remarks, observations, recommendations

Submit photographs with the sanitary inspection form as required.

I V. INSPECTION DETAILS

Name of inspector: ....

Organization of inspector: ....

Designation/title of inspector: ....

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

Name of water supply representative: ....

Signature (if available): .... Date: ....

Sanitary Inspection Form: Dug well with a hand pump (Draft: 1 May 2020)

Appendix E: WHO Sanitary Inspection Form for rainwater harvest

Sanitary Inspection Form (Draft: 1 May 2020) **DRINKING-WATER**

Rainwater collection and storage

1. GENERAL INFORMATION

A. Rainwater system location and specification

(Record information on the rainwater system location and specification. Add "N/A" where information is not applicable.)

Village /town	Community	District

Additional location information: (If using coordinates, state the type and unit e.g. national grid reference coordinates; GPS coordinates.)	

Year of spring construction	**Approximate number of households served by this water supply**: (Circle one of the options below.)					
	1-5	**6-10**	**11-15**	**16-20**	**21-25**	**26-30**

B. System functionality

(Circle Yes or No to indicate whether water is currently available from the rainwater collection system. If No, provide details (e.g. faulty or missing component, no/limited water available etc.) and skip to Section II. Record key remedial actions in Section III that are needed to ensure the rainwater system can provide water.

Is water currently available from the rainwater system?		If No, details (and skip to Section II):
Yes	No	

C. Weather conditions during the 48 hours prior to inspection

(Indicate the predominant temperature and precipitation conditions during the 48 hours prior to inspection by placing a circle around the options below. Where conditions have been changeable, more than one option may be circled. Additional information may be recorded in Section III.)

Temperature	<0o Celsius	0-15° Celsius	15-30° Celsius	>30° Celsius
Precipitation	Snow	Heavy rain	Rain	Dry

D. Water sample information

(Use the table below to record details of any water sample taken during the inspection. Include information for any parameters tested. Add "N/A" where information is not applicable. Additional parameters may be recorded in Section III.)

Sample taken?		Sampling location	Sample no. /code	Other sample information
No	Yes			

Parameter tested	E. coli			
Result and units				

E. Water treatment prior to abstraction/collection

(Answer the question by ticking (3) the appropriate box and providing further information, where applicable.)

☐ No treatment applied at the well

☐ Chlorine applied directly to the well. If so, describe (e.g. chlorine dose, frequency):

☐ Other. Describe (e.g. method, frequency):

Notes:

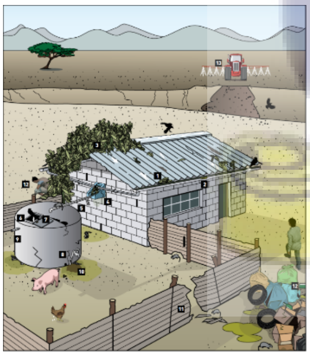
1. If there are more dug well sources in your community, or if other water sources are used by the community (e.g. springs, boreholes), carry out individual sanitary inspections for these sources as well using the relevant sanitary inspection forms.
2. If users store water in the household, also carry out sanitary inspections using the form “Household practices”.

Sanitary Inspection Form

II. Sanitary inspection

IMPORTANT: Read the following notes before undertaking the sanitary inspection

1. Answer the questions by ticking (√) the appropriate box. For guidance, refer to the numbered risk factors in the illustration below, which are linked to each question on the next page. Note: these are typical risk factors; consider what additional risk factors may be relevant in your local context. Refer also to the Technical Fact Sheet for information on the individual components of the rainwater collection system.
2. If there is no risk present, or a question does not apply to the rainwater collection system being inspected, tick the NO box.
3. If a risk is present, tick the YES box. For important situations that require attention, record the actions to be taken in the column provided. These notes can be used to develop a detailed improvement plan, outlining what will be done, by whom, by when and what resources are required. For guidance, refer to the Management Advice Sheet. Where possible, corrective actions should focus on addressing the most serious risks first. Consider low/no cost improvements that can be made immediately.



Sanitary Inspection Form DRINKING-WATER

Sanitary inspection questions		NO	YES (RISK)	What action is needed?
Answer the following questions 1-11 for all types of spring structures				
1	**Are there any visible contaminants (e.g. vegetative material, animal waste) on the roof or guttering channels?** Contaminants on the roof or guttering channels may be washed into the storage tank during rainfall events and constitute a risk to water quality.			
2	**Are the roof or guttering channels inadequately sloped, which may result in the ponding of stagnant water?** The absence of a downward slope on the roof and/ or guttering channels for water to drain towards the storage tank could result in stagnant water, which may subsequently introduce contaminants to the storage tank			
3	**Is there any vegetation or structures overhanging the roof?** Overhanging vegetation, balconies or telephone/electrical wires could attract animals that may contaminate the roof catchment area with faecal material. Fallen foliage could also block gutters and filters.			
4	**Is a filter box missing or inadequate to prevent debris entering the storage tank?** A missing or damaged filter box may allow pieces of debris to enter the storage tank. If the filter box is clogged and/ or unclean, this may cause a blockage/overflow, as well as increase the risk of contaminating the storage tank.			
5	**Is the first flush systema missing or inadequate to prevent contaminants entering the storage tank?** If the first flush system is missing or damaged, the first flush of rainwater (i.e. typically lesser quality) will enter the storage tank and may constitute a risk to water quality. If the first flush system is clogged and/or unclean, this may cause a blockage/overflow, as well as increasing the risk of contaminating the storage tank.			
6	**Does the inside of the storage tank contain any visible signs of contaminants (e.g. animals and/or their waste, sediment accumulation)?** The presence of animals or their wastes in the storage tank constitutes a serious risk to water quality. Sediments may contain microbial pathogens and other contaminants (such as metals) that can impact the safety or acceptability of the stored water. (Note – if there is no inspection port, meaning an internal visual inspection of the storage tank is not possible, record this in Section III.)			
7	**Is there any point of entry to the storage tank that is inadequately covered or sealed?** If the storage tank is inadequately covered or sealed at any point (e.g. cracked tank or damaged or missing inspection port lid), this may allow contaminants (e.g. vermin) to enter the tank. Such openings may also allow light to enter the tank, which can result in algal growth within.			
8	**Is the storage tank tap leaking or otherwise defective?** A leaking or defective tap may increase the risk to water quality by providing a route for contaminants to enter the storage tank.			
9	**Is the overflow pipe inadequately covered to prevent contaminants entering the storage tank?** If the overflow pipe is not covered with a screen (e.g. with a mesh or gauze), or the screen is damaged, vermin may enter the storage tank.			
10	**Is there stagnant water in the water collection area?** Stagnant water in the water collection area increases the likelihood of contaminants entering the storage tank and/ or contaminating collection containers			
11	**Is the fencing or barrier around the storage tank missing or inadequate to prevent animals entering the collection area?**			

	If the fencing or barrier around the storage tank is absent, broken, or poorly constructed (e.g. with wide gaps), animals could enter and damage or contaminate the collection area.			
12	**Can signs of other sources of pollution be seen within 15 meters of the storage tank or water collection area (e.g. animals, rubbish, human settlement, open defecation, fuel storage)?** Animal or human faeces on the ground close to the collection area constitute a serious risk to water quality. Presence of other waste (e.g. household, agricultural, industrial etc.) also constitute a risk to water quality.			
13	**Is there local activity (e.g. industry or agriculture) that could contaminate the roof?** Airborne contaminants such as industrial emissions or spray drifts from local agricultural practices (e.g. crop spraying, slurry spreading or burning) may contaminate the roof catchment area.			

Total number of risks identified: .... /13

Total risk score (# of y) ……………. out of 11

Risk Score 0-3 = low; 4-6 =medium;7- 9 = high; 10-13 =very high

III ADDITIONAL DETAILS – remarks, observations, recommendations

Submit photographs with the sanitary inspection form as required.

I V. INSPECTION DETAILS

Name of inspector: ....

Organization of inspector: ....

Designation/title of inspector: ....

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

Name of water supply representative: ....

Signature (if available): .... Date: ....

Sanitary Inspection Form: Dug well with a hand pump (Draft: 1 May 2020)

Appendix F: WHO Sanitary Inspection Form for household practices, collection, storage, treatment and handling.

Sanitary Inspection Form (Draft: 1 May 2020) **DRINKING-WATER**

Household practices
Collection, storage, treatment and handling

1. GENERAL INFORMATION

A. Household location and information (Record information on household location and population. Add "N/A" where information is not applicable.)		
Village /town	Community	District

Additional location information: (If using coordinates, state the type and unit e.g. national grid reference coordinates; GPS coordinates.)	
Number of people living in this household:	

B. Weather conditions during the 48 hours prior to inspection
(Indicate the predominant temperature and precipitation conditions during the 48 hours prior to inspection by placing a circle around the options
below. Where conditions have been changeable, more than one option may be circled. Additional information may be recorded in Section III.)

Temperature	<0o Celsius	0-15º Celsius	15-30º Celsius	>30º Celsius
Precipitation	Snow	Heavy rain	Rain	Dry

C. Water sample information
(Use the table below to record details of any water sample taken during the inspection. Include information for any parameters tested.
Add "N/A" where information is not applicable. Additional parameters may be recorded in Section III.)

Sample taken?		Sampling location	Sample no. /code	Other sample information	
No	Yes				
Parameter tested		E. coli			
Result and units					

D. Source of water
(Answer the question by ticking (3) the appropriate box and providing further information where applicable. Where multiple sources are used, more than one option may be ticked.)

Dug well	Spring	Surface water (e.g. river, pond)
Borehole	Rainwater collection	Tube well
Other. Describe:		
Additional source location information: (If using coordinates, state the type and unit e.g. national grid reference coordinates; GPS coordinates.)		

E. Water treatment – household level
(Answer the question by ticking (√) the appropriate box and providing further information, where applicable.)

No treatment applied at household level		Treatment applied at household level (Describe by ticking the appropriate box. More than one box may be ticked.)		
Boiling	Chlorination	Solar disinfection	Pasteurization	UV
Membrane filtration	Bio sand filtration	Ceramic filtration	Arsenic removal filters	Fluoride removal filters
Other. Describe:		Where treatment is applied, describe the frequency:		

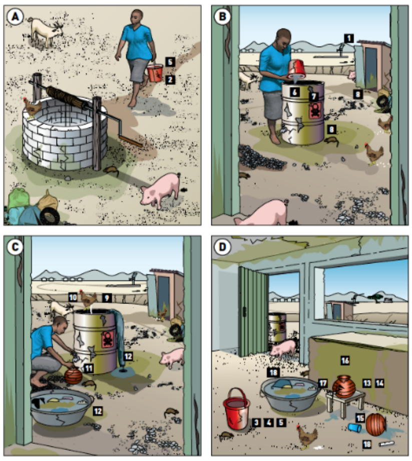
Notes: Using the relevant forms, carry out individual sanitary inspections for the sources of water (e.g. springs, boreholes) that supply the
household (see section D above). If water is piped into the household or collected from a public tap-stand, carry out an inspection using the
"Piped distribution" form.

Sanitary Inspection Form

II. Sanitary inspection

IMPORTANT: Read the following notes before undertaking the sanitary inspection

1. Answer the questions by ticking (3) the appropriate box. For guidance, refer to the numbered risk factors in the illustration below, which are linked to each question on the next page. Note: these are example risk factors only; consider what additional risk factors may be relevant in your local context. Refer also to the Technical Fact Sheet for information on the individual components relating to household drinking-water practices.
2. If there is no risk present, or a question does not apply to the spring being inspected, tick the NO box.
3. If a risk is present, tick the YES box. For important situations that require attention, record the actions to be taken in the column provided. These notes can be used to develop a detailed improvement plan, outlining what will be done, by whom, by when and what resources are required. For guidance, refer to the Management Advice Sheet. Where possible, corrective actions should focus on addressing the most serious risks first. Consider low/no cost improvements that can be made immediately.



Sanitary Inspection Form DRINKING-WATER

Sanitary inspection questions		NO	YES (RISK)	What action is needed?
Answer the following questions 1-11 for all types of spring structures				
1	**Is drinking-water collected from more than one source?** Collecting water from multiple sources increases the likelihood that one of the sources will be unprotected (e.g. open dug well) and vulnerable to contamination.			
Collection container				
2	**Is the collection container cracked, leaking or unclean?** A damaged or unclean collection container may provide an entry route for contaminants during collection.			
3	**Is the backfill area eroded or prone to erosion due to the absence of vegetation?** Is the collection container used to store any liquids other than drinking water? Storage of liquids other than drinking-water in the collection container, including water of lesser quality, increases the likelihood of cross contamination			
4	**When not in use, is the collection container kept in a place where it may become contaminated?** Improper storage of the collection container (e.g. on the ground where animals and children may easily access it, or near sanitation facilities) increases the likelihood of contaminants entering the container, especially when household sanitation practices are poor.			
5	**Is the collection container inadequately covered to prevent the entry of contaminants?** A missing or damaged cover increases the likelihood of contaminants entering the collection container			
Bulk storage container				
6	**Is the bulk storage container cracked, leaking or unclean?** A damaged (e.g. with deep cracks) or unclean bulk storage container may provide an entry route for contaminants during storage.			
7	**Is the bulk storage container used to store any liquids other than drinking-water?**			

	Storage of liquids other than drinking-water in the bulk storage container, including water of lesser quality, increases the likelihood of cross contamination			
8	**Is the bulk storage container located in a place where it may become contaminated?** Locating the bulk storage container close to sources of contaminants (e.g. directly on the ground, or near sanitation facilities) increases the likelihood of contaminants entering the container.			
9	**When not being filled, is the bulk storage container inadequately covered to prevent the entry of contaminants?** A missing or damaged cover increases the likelihood of contaminants entering the bulk storage container			
10	**Are there any visible signs of contaminants inside the bulk storage container (e.g. animals and/or their waste, sediment accumulation)?** The presence of animals or their waste constitutes a serious risk to water quality. Sediments may contain harmful microorganisms and other contaminants (such as metals) that can be resuspended and impact the safety or acceptability of the water.			
11	**Is the tap or utensil used to draw/collect water from the bulk storage container inadequate or unclean?** An unclean or broken tap may contaminate the bulk storage container. Storage of a utensil (e.g. ladle, pot, bucket) in an unsanitary manner (e.g. on the ground), or using the utensil for household purposes other than drinking-water, also increases the likelihood of contaminants entering the container.			
12	**Is the water from the bulk storage container directly used for purposes other than drinking-water (e.g. washing or bathing)?** Drinking-water may be contaminated during washing or bathing (e.g. by dirty hands or soiled garments). Spilt washing-/bathing-water may also collect in the area and provide a source of contaminants.			
Final storage container				
13	**Is the final storage container cracked, leaking or unclean?** A damaged or unclean final storage container may provide an entry route for contaminants during storage			
14	**Is the final storage container used to store any liquids other than drinking-water?** Storage of liquids other than drinking-water in the final storage container, including water of lesser quality, increases the likelihood of cross contamination.			
15	**Is the final storage container kept in a place where it may become contaminated?** Locating the final storage container close to sources of contaminants (e.g. close to, or on the ground) increases the likelihood of contaminants entering the container, especially when household sanitation practices are poor.			
16	**When not being filled, is the final storage container inadequately covered to prevent entry of contaminants?** A missing or damaged cover increases the likelihood of contaminants entering the final storage container			

17	**Is the tap or utensil used to draw/collect water from the final storage container inadequate or unclean?** An unclean or broken tap may contaminate the final storage container. Storage of a utensil (e.g. ladle, pot, bucket) in an unsanitary manner (e.g. on the floor), or using the utensil for household purposes other than drinking-water, also increases the likelihood of contaminants entering the container.			
18	**Is the water from the final storage container directly used for purposes other than drinking-water (e.g. washing or bathing)?** Drinking-water may be contaminated during washing or bathing (e.g. by dirty hands or soiled garments). Spilt washing-/bathing-water may also collect in the area and provide a source of contaminants.			
Household treatment				
19	**If household-level treatment is practiced, is there evidence that it is being carried out ineffectively?** If household treatment is being carried out ineffectively, contaminants may not be adequately removed/inactivated. Note – where possible, ask the household to demonstrate the treatment process during the inspection.			
Total number of risks identified .... /19				

Total risk score (# of y) ……………. out of 11

Risk Score 0-4 = low; 5-9=medium; 10-14 = high; 15-19 =very high

III ADDITIONAL DETAILS – remarks, observations, recommendations

Submit photographs with the sanitary inspection form as required.

I V. INSPECTION DETAILS

Name of inspector: ....

Organization of inspector: ....

Designation/title of inspector: ....

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

Name of water supply representative: ....

Signature (if available): .... Date: ....

Sanitary Inspection Form: Household practices (Draft: 6 March 2020)

Appendix G: Consent Form

INTERVIEW GUIDE CONSENT FORM

Title: **[DETERMINANTS OF HOUSEHOLDS' ACCESS TO IMPROVED WATER SOURCES IN TALENSI DISTRICT WITH FOCUS ON GEOSPATIAL MODELLING AND WATER QUALITY MONITORING]**

Name(s) and affiliation(s) of researcher(s):

This study is being conducted by Prof. Duah Dwumorh, Prof. Mawuli Dzodzomenyo and Maame Serwa Opare-Boafo of the University of Ghana, School of Public Health, Legon-Accra, and Prof. Jim Wright of University of Southampton, Department of Geography and Environment.

You are being invited to part take in the research study above. It is important for you to understand why the above research study is being conducted and what it involves. This will enable you to decide whether you would like to take part in the study or not. Please carefully read the information below and ask any question for further clarification. You can also discuss it with others, but it is up to you to decide whether to take part. If you are happy to participate you will be asked to sign a volunteer agreement form.

General Information about Research

We are seeking your consent to participate in a study that seeks to assess the "**trends and determinants of changes in households' access to improved water sources in dryland areas of Northern Region and determine the resilience of existing water source facilities to climate change as well as current and future adaptation measures by community members.**" This will enable us to recommend alternative designs and management practices that enhances the capacity of community members to adapt to the risk posed by climate change and promote environmental sustainability. With this information we aim to help water sources facilities from extreme temperatures of the climate and provide information of the impacts of extreme events water facilities or sources for policy. The study is funded by the 'Building REsearch Capacity for sustainable water and food security in drylands of Sub-Saharan Africa' (BRECcIA) project, which is supported by UK Research and Innovation as part of the Global Challenges Research Fund. The study is a collaboration between the University of Ghana School of Public Health and School of Geography and Environmental Science, University of Southampton. You have been asked to participate in this research study because you have stayed in this community for more than 10 years and we would like to hear about your experiences with access to improved water sources and the changes of access to improved water source that has occurred over the past ten years, as well as your communities current and future adaptation measures.

Possible Risks and Discomforts

Participation in this study will involve very minimal risk. An inconvenience of this study is the time needed to participate in the interview. The interview will take 15 minutes.

Possible Benefits

There will be no direct benefit to you from this study, but this study is expected to generate information to address the issue of water security in dry lands of Northern Ghana, the impact of climate change events on the water sources. It will also provide information and recommendations about organic and inorganic contamination of water sources, which could help you and others here in planning how and when you use water. Therefore, you are likely to benefit indirectly as a citizen.

Confidentiality

Your privacy is very important to our research team. We appreciate your participation and all the information collected from you during this study will remain confidential. We will be collecting your name and contact information so that we can re-contact you to validate the findings, if need be. If you would prefer, we not re-contact you, you can refuse with no penalty. If you provide us with your name and contact information, your name will not be linked to your responses in the interview. Additionally, no specific information that identifies you will be included in any written reports of this study*”*.

Compensation

If you agree to participate in the in-depth interview, you will receive a token gift of call credit (US approximately $5) after participating.

Additional Cost

There are no costs to you for participating in this study unless your time.

Voluntary Participation and Right to Leave the Research

Your participation in this interview is entirely voluntary. You may withdraw from the study at any time without penalty or loss of benefits to which you are otherwise entitled. You may also withdraw up till the end of the study without providing a reason. If you are uncomfortable with any of the questions that are asked, you do not have to answer those questions.

Contacts for Additional Information

If you have any further questions about the study, you can contact the University of Ghana, School of Public Health as follows:

Dr. Duah Dwomoh
School of Public Health.
University of Ghana, Legon.
Tel: 020-8376845

Your rights as a Participant

This research has been reviewed and approved by the Institutional Review Board of Noguchi Memorial Institute for Medical Research (NMIMR-IRB) and University of Southampton ERGO II – Ethics and Research Governance. If you have any questions about your rights as a research participant, you can contact the IRB Office between the hours of 8am-5pm through the landline 0302916438 or email addresses: nirb@noguchi.ug.edu.gh

Appendix H: SUPPLEMENTARY DATA

Table 1: Sociodemographic characteristics of qualitative study participants in Talensi District

Characteristics of Participants		Number of Participants	
Key informant		Focus Group Discussion	
Total		50	
District/ Community			
Talensi	8		
Kejetia	1	20	
Balungu	1	20	
Total	**10**	**40**	**50**
Sex			
Male	1	21	
Female	9	19	
Total	**10**	**40**	**50**
Age			
<29	-	2	
30-39	2	21	
40-49	3	7	
50-59	4	10	
60+		1	
Total			**50**
Education Level			
No formal	-	13	
Primary /JHS	-	16	
Middle School/SHS/Secondary	1	11	
Tertiary	9	-	
Total	**10**	**40**	**50**
Length of Stay in Institution/Community			
<9	6	8	
10-29	2	30	
30-39	2	2	
40+	-		
Total	**10**	**40**	**50**

Table 2a. Physcochemical parameters of water samples from Talensi during rainy and dry season.

Sample No	**pH (Rainy Season) pH-scale**	p H (Dry Season) **pH-scale**	**Temp (Rainy Season)** ºC	Temperature (Dry Season) ºC	**Conductivity (Rainy Season)** µS/cm	Conductivity (Dry Season) µS/cm	**Total Dissolved Solids (Rainy Season)** mg/l	Total Dissolved Solids (Dry Season) mg/l
S1	6.86	7.23	25.93	**30.60**	**464.80**	**425.50**	228.80	210.80
S2	7.55	7.93	25.93	**30.70**	345.50	324.90	169.20	158.50
S3	7.02	7.45	25.93	**30.80**	**412.10**	**406.80**	202.00	200.80
S4	7.40	7.59	25.93	**30.50**	**505.70**	**500.60**	247.90	245.10
S5	7.46	7.27	25.93	**30.70**	**475.40**	**447.00**	232.80	217.80
S6	7.45	7.31	25.93	**30.70**	**475.30**	**416.70**	233.00	205.00
S7	7.52	7.81	25.93	**31.00**	**455.20**	**441.40**	222.90	215.80
S8	8.35	7.84	25.93	**31.00**	357.60	325.70	175.90	159.90
S9	8.00	7.91	25.93	**31.10**	353.30	327.40	173.00	159.50
S10	7.92	7.93	25.93	**31.10**	361.40	353.70	177.30	174.00
S11	7.69	7.74	25.93	**31.00**	177.80	**405.00**	87.14	197.70
S12	7.91	7.95	25.93	**30.40**	**407.50**	**400.30**	199.60	196.50
S13	8.26	8.09	25.93	**30.30**	384.40	**418.50**	188.70	203.90
S14	7.57	8.51	25.93	**31.10**	**528.80**	**488.50**	259.50	238.80
S15	7.96	7.91	25.93	**31.70**	**540.00**	**422.20**	264.30	207.60
S16	7.76	7.52	25.93	**31.10**	**516.80**	**497.60**	253.50	243.60
S17	8.06	8.14	25.93	**31.10**	**467.50**	**493.70**	228.90	243.80
S18	7.82	8.13	25.93	**31.10**	**471.90**	**499.40**	232.10	245.20
S19	8.50	7.91	25.93	**30.10**	335.40	**435.70**	164.10	213.10
S20	7.54	7.64	25.93	**30.20**	291.80	**615.70**	143.20	302.30
S21	7.84	7.93	25.93	**30.20**	63.52	**468.50**	**31.10**	228.90
S22	7.63	8.22	25.93	**30.20**	**417.80**	415.10	205.00	204.10
S23	8.43	8.11	25.93	**30.20**	392.50	**438.30**	191.50	214.30
S24	8.19	7.95	25.93	**30.90**	396.40	**409.40**	194.40	201.20
S25	7.95	7.61	25.88	**30.70**	**402.80**	294.10	197.40	143.60

S26	7.23	6.78	25.88	**31.00**	**69.58**	193.10	**34.10**	94.29
S27	7.36	8.05	25.88	**31.00**	**607.20**	378.80	297.00	186.10
S28	7.78	7.38	25.88	**31.20**	397.60	**618.50**	197.00	302.40
S29	6.88	8.14	25.88	**31.20**	249.60	288.40	122.30	141.90
S30	7.25	7.76	25.88	**31.00**	**548.70**	**495.00**	269.90	241.20
S31	7.79	7.90	25.88	**30.30**	**475.10**	**491.10**	232.80	241.60
S32	7.97	7.93	25.88	**31.10**	181.30	353.70	88.81	174.00
S33	8.06	7.74	25.88	**31.00**	**474.60**	**405.00**	232.40	197.70
S34	6.88	7.95	25.93	**30.40**	8.42	**400.30**	**4.09**	196.50
S35	7.94	7.56	25.93	**30.20**	**477.70**	350.80	233.40	172.00
S36	7.87	7.97	25.93	**30.80**	312.90	335.70	153.70	164.80
S37	6.68	7.48	25.93	**30.90**	7.30	**546.80**	**3.58**	267.00
S38	6.47	7.85	25.93	**31.10**	25.88	**924.80**	**12.69**	456.90
S39	6.44	8.00	27.98	**31.00**	5.99	349.20	**2.92**	171.20
S40	6.71	7.87	27.98	**31.20**	5.88	**1002.00**	**2.88**	491.80
S41	6.88	8.15	27.98	**30.20**	24.11	350.30	**11.79**	171.00
S42	6.54	7.67	27.98	**31.20**	12.65	**662.50**	**6.22**	324.00
S43	6.67	7.39	27.98	**31.20**	**1026.00**	**1053.00**	502.00	518.60
S44	6.59	7.53	27.98	**30.20**	791.70	**800.10**	389.20	392.30
S45	8.16	7.48	27.98	**30.20**	476.10	338.10	232.90	165.60
S46	8.22	7.95	27.98	**30.70**	312.10	349.50	153.10	171.60
S47	7.53	6.94	27.98	**30.70**	130.40	**662.80**	63.69	324.00
S48	6.93	7.53	27.98	**30.20**	689.70	**800.10**	338.20	392.30
S49	7.32	7.90	27.98	**30.30**	484.40	**491.10**	236.90	241.60
S50	7.84	7.84	27.98	**30.90**	689.70	**554.30**	273.40	273.40
Min	6.4	6.78	25.88	30.1	5.9	193.1	2.9	94.3
Median	7.6	7.86	25.93	30.75	400.2	439.85	197.2	215.05
Max	8.5	8.52	27.98	31.7	1026	1053	502	518.6

Table 2b: Chemicals and trace metals parameters of water samples from Talensi during rainy and dry season

Sample No	**Nitrate-N (Rainy Season)** mg/l	Nitrate-N (Dry Season) mg/l	**Fluoride (Rainy Season)** mg/l	Fluoride (Dry Season) mg/l	**Arsenic (Rainy Season)** mg/l	Arsenic (Dry Season) mg/l	**Lead (Rainy Season)**	Lead (Dry Season)	**Mercury (Rainy Season)** mg/l	Mercury (Dry Season) mg/l
S1	4.20	**36.00**	0.41	0.08	0.0005	bdl	bdl	bdl	bdl	0.0007
S2	2.30	1.40	0.50	0.12	bdl	bdl	bdl	bdl	bdl	0.0007
S3	2.50	2.70	0.38	0.08	0.0001	0.0033	bdl	bdl	bdl	0.0007
S4	2.80	6.10	2.40	**2.00**	0.0006	bdl	bdl	bdl	bdl	0.0006
S5	**28.00**	**50.00**	0.44	0.19	bdl	bdl	bdl	bdl	bdl	0.0004
S6	**25.00**	**48.00**	0.43	0.19	bdl	bdl	bdl	bdl	0.0003	0.0003
S7	**20.00**	**35.00**	0.49	0.27	0.0002	0.0045	bdl	bdl	0.0001	0.0004
S8	0.50	1.80	0.54	0.22	0.0005	bdl	bdl	bdl	0.0000	0.0006
S9	0.82	2.00	0.52	0.24	0.0004	bdl	bdl	bdl	0.0000	0.0005
S10	0.42	1.50	0.56	0.25	0.0011	0.0039	bdl	bdl	0.0000	0.0008
S11	1.20	3.00	0.30	0.19	0.0006	0.0005	bdl	bdl	bdl	0.0008
S12	0.25	2.90	0.45	0.19	0.0001	0.0012	bdl	bdl	bdl	0.0009
S13	0.24	3.10	0.46	0.17	0.0005	0.0056	bdl	bdl	bdl	0.0009
S14	2.20	4.40	**2.20**	**1.50**	0.0018	0.0073	bdl	bdl	bdl	0.0002
S15	1.50	**13.00**	**2.10**	0.69	0.0025	0.0000	bdl	bdl	bdl	0.0002
S16	1.50	9.90	**2.50**	**1.60**	0.0023	bdl	bdl	bdl	bdl	0.0002
S17	1.50	**11.00**	**4.80**	**3.80**	0.0010	bdl	bdl	bdl	bdl	0.0002
S18	4.50	**10.00**	**4.60**	**3.80**	0.0016	bdl	bdl	bdl	bdl	0.0002
S19	1.70	2.80	0.49	0.10	0.0016	0.0019	bdl	bdl	bdl	bdl
S20	0.45	1.10	0.71	0.63	0.0026	bdl	bdl	bdl	bdl	bdl
S21	3.30	0.89	0.25	1.10	0.0035	bdl	bdl	bdl	bdl	0.0007
S22	0.77	2.40	1.00	0.10	0.0015	bdl	bdl	bdl	bdl	0.0007
S23	6.10	2.70	0.54	0.08	0.0026	bdl	bdl	bdl	bdl	0.0007
S24	3.50	3.60	0.53	0.10	0.0025	0.0019	bdl	bdl	bdl	0.0004
S25	**13.00**	2.10	0.50	0.12	0.0018	0.0019	bdl	bdl	bdl	0.0007
S26	2.50	1.90	0.30	0.05	0.0014	bdl	bdl	bdl	bdl	0.0003

S27	2.70	2.80	**1.60**	0.57	0.0037	bdl	bdl	bdl	bdl	0.0001
S28	4.10	3.00	0.58	0.12	0.0020	0.0040	bdl	bdl	bdl	bdl
S29	1.60	1.70	0.38	0.07	0.0022	0.0015	bdl	bdl	bdl	0.0000
S30	3.60	9.00	**1.80**	**3.80**	0.0019	bdl	bdl	bdl	bdl	0.0014
S31	1.30	2.40	**5.30**	**2.40**	0.0028	bdl	bdl	bdl	bdl	0.0009
S32	1.50	1.50	0.87	0.25	0.0002	0.0039	bdl	bdl	bdl	0.0008
S33	6.30	3.00	5.50	0.19	0.0022	0.0005	bdl	bdl	0.0000	0.0008
S34	1.40	2.90	0.17	0.19	bdl	0.0012	bdl	bdl	0.0001	0.0009
S35	4.70	1.90	0.96	0.20	0.0017	bdl	bdl	bdl	0.0004	bdl
S36	0.77	4.00	0.82	0.31	0.0046	bdl	bdl	bdl	0.0003	0.0005
S37	0.17	**12.00**	0.18	0.36	bdl	bdl	bdl	bdl	0.0003	0.0005
S38	0.37	**66.00**	0.24	0.26	0.0011	0.0025	bdl	bdl	0.0002	0.0005
S39	1.10	2.80	0.23	0.10	0.0002	bdl	bdl	bdl	bdl	0.0003
S40	1.20	**79.00**	0.19	0.22	bdl	bdl	bdl	bdl	0.0000	0.0004
S41	0.58	3.90	0.29	0.14	0.0001	0.0028	bdl	bdl	0.0002	bdl
S42	3.00	5.10	0.21	0.20	0.0001	0.0080	bdl	bdl	0.0010	0.0006
S43	6.80	2.30	0.65	0.19	0.0022	bdl	bdl	bdl	0.0027	0.0005
S44	2.60	**15.00**	0.74	0.13	0.0067	**0.0494**	bdl	bdl	0.0008	bdl
S45	**11.00**	2.20	1.20	0.22	0.0039	bdl	bdl	bdl	0.0012	bdl
S46	4.50	3.80	1.30	0.24	0.0034	bdl	bdl	bdl	0.0009	bdl
S47	5.30	1.80	0.55	0.16	0.0015	bdl	bdl	bdl	0.0007	0.0006
S48	**15.00**	**15.00**	0.78	0.13	**0.0310**	**0.0494**	bdl	bdl	0.0002	bdl
S49	8.40	2.40	**2.50**	**2.40**	0.0008	bdl	bdl	bdl	0.0008	0.0009
S50	4..45	1.50	0.78	0.83	bdl	bdl	bdl	bdl	0.0003	0.0001
Min	0.17	0.89	0.17	0.05	0	0	bdl	bdl	0	0
Median	2.5	3	0.5	0.22	0.0016	0.003	bdl	bdl	0.0003	0.0005
Max	28	79	5.5	3.8	0.031	0.049	bdl	bdl	0.0027	0.014

Table 2c. Microbial parameters of water samples from Talensi during rainy and dry season

Sample No	**Total coliform (Rainy Season)**	Total coliform (Dry Season)	**Fecal Enterococci (Rainy Season)**	Fecal Enterococci (Dry Season)	**E. coli, (Rainy Season)**	*E. coli (Dry Season)*	**Salmonella spp, (Rainy Season)**	Salmonella spp (Dry Season)	**Shigella spp, (Rainy Season)**	Shigella spp (Dry Season)
S1	153.00	92.00	12.00	ND	30.00	ND	ND	ND	ND	ND
S2	34.00	ND	8.00	ND	6.00	ND	ND	ND	28.00	ND
S3	13.00	ND	11.00	ND	3.00	ND	ND	ND	ND	ND
S4	480.00	185.00	72.00	60.00	210.00	101.00	12.00	ND	ND	ND
S5	191.00	77.00	64.00	ND	122.00	ND	34.00	ND	ND	ND
S6	157.00	19.00	37.00	48.00	60.00	ND	ND	ND	ND	ND
S7	88.00	85.00	68.00	ND	12.00	ND	6.00	ND	ND	ND
S8	181.00	36.00	112.00	21.00	5.00	ND	ND	ND	ND	ND
S9	174.00	166.00	96.00	93.00	109.00	ND	8.00	ND	ND	ND
S10	131.00	238.00	104.00	ND	63.00	ND	ND	ND	ND	ND
S11	166.00	94.00	44.00	ND	71.00	40.00	ND	ND	14.00	ND
S12	97.00	60.00	59.00	ND	49.00	ND	ND	ND	ND	ND
S13	189.00	92.00	95.00	ND	103.00	ND	ND	ND	ND	ND
S14	173.00	274.00	348.00	10.00	112.00	92.00	2.00	ND	ND	ND
S15	118.00	96.00	102.00	ND	54.00	ND	ND	ND	ND	ND
S16	90.00	82.00	66.00	ND	38.00	ND	11.00	ND	ND	ND
S17	147.00	ND	ND	ND	73.00	ND	ND	ND	ND	ND
S18	186.00	148.00	ND	ND	51.00	ND	ND	ND	41.00	ND
S19	148.00	17.00	ND	55.00	5.00	7.00	26.00	30.00	10.00	3.00
S20	224.00	188.00	ND	32.00	112.00	20.00	4.00	ND	57.00	7.00
S21	195.00	240.00	138.00	ND	90.00	59.00	18.00	ND	30.00	ND
S22	149.00	181.00	185.00	75.00	66.00	6.00	3.00	ND	ND	ND
S23	93.00	173.00	155.00	ND	24.00	18.00	ND	ND	ND	ND
S24	70.00	9.00	37.00	31.00	15.00	ND	ND	ND	ND	ND
S25	109.00	78.00	110.00	102.00	45.00	ND	27.00	ND	ND	ND

S26	**242.00**	**296.00**	**160.00**	**122.00**	**92.00**	ND	**110.00**	**78.00**	**132.00**	ND
S27	**12.00**	ND	26.00	ND	ND	ND	ND	ND	**43.00**	ND
S28	**46.00**	ND	ND	18.00	14.00	ND	ND	ND	**7.00**	ND
S29	**197.00**	**159.00**	**91.00**	**63.00**	**78.00**	**71.00**	**27.00**	ND	ND	ND
S30	**62.00**	ND	ND	19.00	ND	ND	ND	ND	ND	ND
S31	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
S32	**112.00**	**238.00**	**104.00**	**16.00**	**45.00**	ND	ND	ND	ND	ND
S33	ND	**94.00**	ND	ND	**40.00**	ND	ND	ND	**10.00**	**4.00**
S34	**167.00**	**60.00**	**17.00**	ND	**98.00**	ND	**9.00**	ND	ND	ND
S35	**309.00**	**27.00**	**93.00**	ND	**142.00**	**10.00**	ND	ND	ND	ND
S36	**386.00**	**141.00**	**80.00**	ND	**165.00**	**63.00**	**11.00**	ND	**38.00**	ND
S37	**193.00**	**72.00**	**149.00**	ND	**12.00**	**44.00**	ND	ND	ND	ND
S38	**106.00**	**92.00**	**122.00**	**42.00**	**28.00**	**10.00**	**18.00**	ND	ND	ND
S39	**138.00**	ND	ND	ND	26.00	ND	ND	ND	ND	ND
S40	**382.00**	**178.00**	ND	**87.00**	**166.00**	ND	**23.00**	ND	**7.00**	ND
S41	**182.00**	ND	ND	ND	**55.00**	ND	ND	**13.00**	ND	ND
S42	**30.00**	ND	ND	ND	ND	ND	ND	ND	ND	ND
S43	**102.00**	**74.00**	**59.00**	ND	**53.00**	**18.00**	ND	ND	**34.00**	ND
S44	**93.00**	**12.00**	**15.00**	ND	**35.00**	**4.00**	**6.00**	ND	0.00	ND
S45	ND	**38.00**	ND	ND	ND	ND	ND	ND	ND	ND
S46	**118.00**	**39.00**	ND	ND	ND	**16.00**	ND	ND	ND	ND
S47	**241.00**	**277.00**	**150.00**	**33.00**	**112.00**	**106.00**	**78.00**	**41.00**	**86.00**	ND
S48	ND	12.00	ND	ND	ND	4.00	ND	ND	ND	ND
S49	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
S50	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Min	0	0	0	0	0	0	0	0	0	0
Median	134.5	75.5	40.5	0	45	0	0	0	0	0
Max	480	296	348	122	210	106	110	78	132	7

Table 3a: Median difference between water contaminants at the main source and households' rainy season.

Water quality parameters	Main source	household	z- Value	P-Value
pH	397	878	-1.253	0.2101
Temperature	402	873	-1.224	0.2209
Electrical conductivity	572	703	2.284	0.0224
Total Dissolved Solids	571.5	703.5	2.274	0.0230
Fluoride	562.5	712.5	2.092	0.0364
Nitrate	588.5	686.5	2.618	0.0088
Arsenic	546	729	1.763	0.0779
Lead	bdl	bdl	bdl	bdl
Mercury	495.5	779.5	0.874	0.3819
Total Coliform	323	952	-2.751	0.0059
Fecal Enterococci	342	933	-2.413	0.0158
E. coli	316	959	-2.899	0.0037
Salmonella spp.	430	845	-0.672	0.5018
Shigella spp.	487	788	0.715	0.4747

Table 3b: Median difference between water contaminants at the main source and households' dry season.

Water quality parameters	Main source	household	Z – Value	P-Value
pH	348	927	-2.245	0.0248
Temperature	412	863	-0.958	0.3380
Electrical conductivity	468.5	806.5	0.192	0.8477
Total Dissolved Solids	467	808	0.162	0.8715
Fluoride	421.5	853.5	-0.760	0.4475
Nitrate	414.5	860.5	-0.900	0.3682
Arsenic	436.5	838.5	-0.514	0.6075
Lead	bdl	bdl	bdl	bdl
Mercury	441.5	833.5	-0.356	0.7215
Total Coliform	366.5	908.5	-1.883	0.0597
Fecal Enterococci	448	827	-0.259	0.7958
E. coli	450	825	-0.212	0.8323
Salmonella spp.	475	800	0.687	0.4919
Shigella spp.	457	818	-0.098	0.9218

Table 4a. CCMEWQI during rainy and dry season

Sample No	WQI Rainy season	Water Quality Status rainy season	WQI Dry season	Water Quality Status Dry season
S1	60.66	Marginal	66.03	Fair
S2	89.73	Good	94.16	Good
S3	82.41	Good	88.33	Good
S4	43.49	Poor	46.21	Marginal
S5	44.94	Poor	65.63	Fair
S6	53.27	Marginal	63.49	Marginal
S7	58.3	Marginal	66.32	Fair
S8	57.99	Marginal	83.82	Good
S9	55.23	Marginal	59.57	Marginal
S10	65.95	Fair	56.09	Marginal
S11	59.01	Marginal	60.59	Marginal
S12	60.32	Marginal	76.75	Fair
S13	54.99	Marginal	72.3	Fair
S14	52.87	Marginal	43.69	Poor
S15	56.12	Marginal	49.05	Marginal
S16	52.55	Marginal	69.08	Fair
S17	58.06	Marginal	75.64	Fair
S18	52.06	Marginal	61.62	Marginal
S19	50.89	Marginal	79.86	Fair
S20	54.81	Marginal	54.43	Marginal
S21	54.5	Marginal	48.03	Marginal
S22	52.15	Marginal	56.67	Marginal
S23	59.45	Marginal	60.51	Marginal
S24	71.18	Fair	80.84	Good
S25	53.44	Marginal	60.17	Marginal
S26	48.65	Marginal	44.38	Poor
S27	66.41	Fair	94.16	Good
S28	82.66	Good	81.71	Good
S29	55.65	Marginal	51.68	Marginal
S30	70.14	Fair	81.26	Good
S31	85.02	Good	82.2	Good
S32	58.75	Marginal	47.83	Marginal
S33	84.79	Good	71.29	Fair
S34	58.97	Marginal	33.2	Poor
S35	48.7	Marginal	86.46	Good
S36	51.6	Marginal	51.06	Marginal
S37	45.6	Marginal	78.45	Fair

S38	61.8	Marginal	61.97	Marginal
S39	96	Excellent	62.51	Marginal
S40	40.6	Poor	59.45	Marginal
S41	57.68	Marginal	96	Excellent
S42	90.72	Good	87.99	Good
S43	54.05	Marginal	67.62	Fair
S44	64.33	Marginal	88.03	Good
S45	88.28	Good	84.8	Good
S46	66.72	Fair	88.5	Good
S47	45.1	Marginal	43.55	Poor
S48	79.29	Fair	66.45	Fair
S49	87.85	Good	82.2	Good
S50	93.51	Good	88.17	Good

Table 5: Estimated Hazard Index for water samples from the study area.

Sample No	HI= As+Hg+F^- (rainy)	HI= As+Hg+F^- (dry)	HI= As+NO_3^- (rainy)	HI= As+NO_3^- (dry)
S1	0.077	**1.614**	0.123	0.643
S2	0.036	0.069	0.041	0.025
S3	0.037	0.441	0.054	0.363
S4	0.229	0.278	0.107	0.109
S5	0.031	**2.236**	0.5	0.893
S6	0.034	**2.146**	0.446	0.857
S7	0.055	**1.995**	0.376	**1.054**
S8	0.086	0.086	0.057	0.032
S9	0.075	0.094	0.053	0.036
S10	0.145	0.446	0.112	0.398
S11	0.079	0.189	0.079	0.101
S12	0.042	0.252	0.014	0.166
S13	0.080	0.680	0.052	0.589
S14	0.329	0.894	0.211	0.774
S15	0.388	0.582	0.265	0.232
S16	0.398	0.444	0.246	0.177
S17	0.438	0.493	0.122	0.196
S18	0.481	0.448	0.233	0.179
S19	0.187	0.306	0.183	0.231
S20	0.298	0.049	0.256	0.020
S21	0.351	0.046	0.392	0.016
S22	0.214	0.114	0.157	0.043
S23	0.286	0.127	0.357	0.048
S24	0.276	0.345	0.301	0.245
S25	0.207	0.281	0.404	0.218
S26	0.155	0.088	0.178	0.034
S27	0.467	0.126	0.401	0.05

S28	0.232	0.515	0.264	0.435
S29	0.237	0.219	0.238	0.173
S30	0.310	0.415	0.245	0.161
S31	0.645	0.116	0.290	0.043
S32	0.081	0.446	0.046	0.398
S33	0.602	0.189	0.322	0.101
S34	0.013	0.252	0.025	0.166
S35	0.234	0.085	0.246	0.034
S36	0.500	0.183	0.452	0.071
S37	0.016	0.540	0.003	0.214
S38	0.124	**3.189**	0.111	**1.417**
S39	0.035	0.128	0.039	0.05
S40	0.014	**3.531**	0.021	**1.411**
S41	0.032	0.441	0.020	0.336
S42	0.025	0.995	0.054	0.853
S43	0.282	0.107	0.331	0.041
S44	0.699	**5.374**	0.685	**4.973**
S45	0.469	0.098	0.568	0.039
S46	0.425	0.170	0.404	0.068
S47	0.189	0.086	0.238	0.032
S48	**3.01**	**5.374**	**3.220**	**4.973**
S49	0.262	0.116	0.226	0.043
S50	0.059	0.070	0.079	0.027

Table 6a: Carcinogenic Risk Associated with Arsenic Exposure

Sample No	Cancer Risk As (rainy)	Cancer Risk As (dry)
S1	1.07E-05	-
S2	-	-
S3	2.14E-06	2.31E-05
S4	1.29E-05	-
S5	-	-
S6	-	-
S7	4.29E-06	3.15E-05
S8	1.07E-05	-
S9	8.57E-06	-
S10	2.36E-05	2.73E-05
S11	1.29E-05	3.50E-06
S12	2.14E-06	8.40E-06
S13	1.07E-05	3.92E-05
S14	3.86E-05	5.11E-05
S15	5.36E-05	-
S16	4.93E-05	-
S17	2.14E-05	-
S18	3.43E-05	-
S19	3.43E-05	1.33E-05
S20	5.57E-05	-
S21	7.50E-05	-
S22	3.21E-05	-
S23	5.57E-05	-
S24	5.36E-05	1.33E-05
S25	3.86E-05	1.33E-05
S26	3.0E-05	-
S27	7.93E-05	-

S28	4.29E-05	2.80E-05
S29	4.71E-05	1.05E-05
S30	4.07E-05	-
S31	6.0E-05	-
S32	4.29E-06	2.73E-05
S33	4.71E-05	3.50E-06
S34	-	8.40E-06
S35	3.64E-05	-
S36	9.86E-05	-
S37	-	-
S38	2.36E-05	1.75E-05
S39	4.29E-06	-
S40	-	-
S41	2.14E-06	1.96E-05
S42	-	5.60E-05
S43	4.71E-05	-
S44	1.44E-04	3.46E-04
S45	8.36E-05	-
S46	7.29E-05	-
S47	3.21E-05	-
S48	6.64E-04	3.46E-04
S49	1.71E-05	-
S50	-	-