UNIVERSITY OF GHANA
COLLEGE OF BASIC AND APPLIED SCIENCES

ECOSYSTEMS' HEALTH AND DIARRHOEA TRANSMISSION PATHWAYS; A CASE STUDY OF SELECTED COASTAL COMMUNITIES IN GHANA

BY

OPOKU SALAMA SYLVIA

(10875163)

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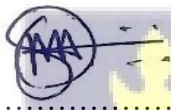
DECLARATION

I, Opoku Salama Sylvia hereby annunciate that this research was carried out by me as part of the requirement for the award of an MPhil Sustainability Science Degree at the Institute for Environment and Sanitation Studies, College of Basic and Applied Science, University of Ghana. This research work has never been presented, either in part or whole for a degree in this university or any other institution. All works, guidelines and documents adopted have been cited and duly acknowledged.



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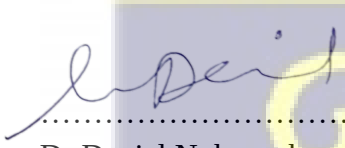
Opoku Salama Sylvia Date

(Student)



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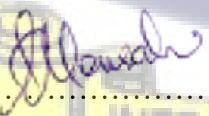
Dr Daniel Nukpezah Date

(Principal Supervisor)



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Dr. Adelina Maria Mensah Date

(Co-Supervisor)

ABSTRACT

Diarrhoea is the passage of three or more loose stools per day mainly caused by the ingestion of bacteria-contaminated water or food. Its prevalence in Ghana transcends to the coastal communities which are vulnerable to contracting it due to poor coastal sanitation concurrently in the wake of climate change impacts. This study aimed to investigate sediments, water and biota in low-lying, climate-impacted coastal marine ecosystems along the Central and Eastern coasts of Ghana as potential diarrhoea transmission pathways. Sediments (n = 234); water (n = 234); biota (n = 78) samples were collected monthly from January to June. Physicochemical and bacteriological analyses of the samples were conducted. The total coliform in water samples ranged from 3.3 x 10^2 to 4.2 x 10^7 CFU/100ml while Escherichia coli (*E. coli*) was up to 1.5 x 10^7 CFU/100ml. With the exception of Anyanui, the *E. coli* levels in all the water samples exceeded the USEPA recreational water quality limit. Likewise, the *E. coli* levels in oysters, fish and sediments exceeded their acceptable limits. Target bacteria present in the samples included Salmonella and Vibrio species. The sediment samples were the most laden with pathogens. The highest coliform counts and pathogens isolated were observed during the rainy season (April to June). Principal component analysis revealed increasing biological oxygen demand, phosphate, sulphate, nitrate, total dissolved solids and decreasing dissolved oxygen correlated with the increasing bacteria count. The findings of this study demonstrate that marine ecosystems may serve as diarrhoea transmission pathways. Further recommended, is the need for a prospective cohort study. The residents did not view the marine ecosystems as diarrhoea transmission pathways making pronounced the need for awareness campaigns and management practices to mitigate coastal pollution and safeguard community health.

DEDICATION

This work is dedicated to the Almighty God for his faithfulness and providence; to my parents, Prof Eric Vernon Opoku and Mrs Faustina Opoku for their sacrifices towards the successful completion of my program; to Dr Daniel Nukpezah for his instrumentality in helping me secure funding from the Ministry of Foreign Affairs of Denmark through the Coastal Community Resilience to Climate Change and Diarrhoea Project (C2RCD) for this research work.

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LIST OF ABBREVIATIONS

BOD	Biological oxygen demand
CFU/ml	Colony forming units per millilitre
CFU/g	Colony forming units per gram
C2RCD	Coastal Community Resilience to Climate Change and Diarrhoea
DO	Dissolved oxygen
E. coli	*Escherichia coli*
EC	Electrical conductivity
FIB	Faecal indicator bacteria
g/L	Gram per litre
IPCC	Intergovernmental Panel on Climate Change
mg/L	Milligram per litre
mS/cm	Millisiemens per centimetre
PCA	Principal component analysis
SP	Species (singular)
SPP	Species (plural)
T.col	Total coliform
TDS	Total dissolved solids
UN	United Nations
US EPA	United Nations Environmental Protection Agency
WHO	World Health Organization

CHAPTER ONE

1.1 INTRODUCTION

Ecosystems are termed life-support systems for all forms of life and human well-being. The services ecosystems render especially to human well-being from its agroeconomic systems, forest ecosystems, grassland ecosystems, and aquatic ecosystems are indispensable. They provide a range of basic needs such as food, water, clean air, shelter, health benefits, and relatively constant climatic conditions. (Corvalan *et al*., 2005; Myers *et al.,* 2013). Ecosystem services, in other words, benefit the human population in terms of social and economic value. It is therefore important that ecosystems operate optimally and are sustained so they can ensure the continuity and survival of their inhabitants.

A healthy ecosystem ideally has its various components interacting and functioning together optimally to provide ecosystem services (Costanza *et al*. 1997; Corvalan *et al*., 2005; Myers *et al*., 2013). However, changes and stresses imposed on their flow of functioning hamper their abilities to provide these services and result in negative secondary impacts which affect social well-being and income flow (Corvalan *et al*., 2005; Myers *et al.,* 2013). Coastal ecosystems, especially in tropical countries of West Africa, are very sensitive in terms of their health status and are more vulnerable to the impact of events like climate change (tidal wave action, storm surges, and floods) in combination with anthropogenic activities (McIver *et al*., 2016; World Bank, 2020). Among the common challenges faced by Ghana's coastal communities, climate change and anthropogenic activities or interventions supersede them all in terms of their effects

(World Bank, 2020). Environmental depletion and pollution brought on by anthropogenic activities like industrialization, agricultural production, and urban activities have negative impacts on the rivers and oceans that are essential for life, eventually harming human health and long-term societal development (Xu *et al*., 2022). An estimated 80% of industrial and municipal wastewater worldwide is released into the environment without any previous treatment impacting ecosystems and human health negatively. Due to the severe lack of sanitation and wastewater treatment systems, this percentage is greater in the least developed nations (Lin *et al*., 2022). These in turn facilitate and elevate the rate at which nutrients make their way into marine ecosystems (Conserve Energy Future, 2022). They also result in microbial pollution which poses a major threat to the environment and public health (Kilinc & Besler, 2014). The impacts of these forms of pollution degrade the coast, endanger ecosystems, jeopardise human livelihoods and well-being, erode productive capacity, and upsurge vulnerability to natural disasters and diseases (World Bank, 2020). Diseases and conditions whose impacts are exacerbated by climate change like heat exhaustion, malnutrition, malaria, and diarrheal diseases according to the 2022 Intergovernmental Panel on Climate Change (IPCC) report, are predicted to cause an additional 250,000 deaths per year by 2050. More than half of this figure is predicted for Africa (Cissé *et al*., 2022).

Diarrhoea, a typical symptom and disease condition of the gastrointestinal tract, is characterized by watery and sometimes bloody stool and can be caused by a wide range of microorganisms, especially bacteria (DuPont, 2014; WHO, 2017). Household sanitation measures, water quality and storage procedures, personal and food hygiene

routines, and bug or pest infestations are major exposure pathways to faecal contaminants And pathogens associated with diarrhoea. In addition to these, components of marine ecosystems such as coastal waterbodies, agriculturally significant marine organisms, and sediments have been in recent times implicated as reservoirs and transmission pathways for diarrhoea-causing microorganisms (WHO, 2003; Fernández-Delgado & Suarez, 2009; Mulamattathil *et al*., 2014; Hassard *et al*., 2016; Sedlacek *et al*., 2016). These are components of marine ecosystems with which human interactions are a necessity for survival and recreation. These contaminants find their way into marine ecosystems through anthropogenic activities like poor management and treatment of solid and liquid waste from urban areas and cities (Mahu *et al*., 2015; Aglanu and Appiah, 2017; Klubi *et al*., 2018). Another contributor to human-induced environmental disturbances particularly in rural and impoverished regions of Sub-Saharan Africa and Asia is open defecation which increases nutrient levels and microbial pollutants of environmental and public health concerns (Kilinc & Besler, 2014; Conserve Energy Future, 2022).

Changes in hydrology and other physicochemical water quality parameters can also affect the pathogens (bacteria, viruses, and protozoa) that cause various diseases and are spread by contact with water (Vidon *et al*., 2008; Cho *et al*., 2010; Ratajczak *et al*., 2010; Chu *et al*., 2011; Liang *et al*., 2013). Significant relationships have been observed between high counts of microbial indicators and parameters such as nitrate, conductivity, total dissolved solids, and dissolved oxygen concentrations (Akita *et al*., 2020). One of the most difficult problems facing society in the twenty-first century is sustaining the health of aquatic environments (Hampel *et al*. 2015). The dynamics that

exist between the various elements (anthropogenic and climatic) within coastal environments are complex. They are also responsible for the consequential introduction of microbial contaminants into coastal waters. These microbial contaminants have pathogens that pose a severe health risk by degrading water quality and fostering the spread of infectious diseases among people and marine life (Shuval, 2003; McLellan & Abdelzaher *et al*., 2010; Eren 2014). This, therefore, makes it imperative that more attention is given to investigating the nature, extent and risks associated with the formation of pathways for disease transmission within coastal marine ecosystems.

1.2 Problem statement

One of the major types of pollution that has a considerable detrimental impact on health and mortality is contamination in aquatic environments (Bashir *et al*., 2020). They also result in microbial pollution which poses a major threat to both the environment and public health (Kilinc & Besler, 2014). Atiteti, Anyanui, Anyako, Mumford and Gbegbeyise (study communities) are low-lying climate change-impacted coastal communities in the central and eastern coasts of Ghana. Their geographical locations make them vulnerable to secondary impacts of climate change which include the spread of disease-causing pathogens and vectors in the face of poor sanitary conditions. These communities also present visible evidence of marine pollution from municipal waste and poor sanitary practices like open defecation and indiscriminate household waste disposal. These contaminants when introduced into coastal and fresh waters can make their way into the water bodies, the sediments and the aquatic fauna, most of which are agriculturally significant species (WHO, 2003; Fernández-Delgado & Suarez, 2009; Mulamattathil *et al*., 2014; Hassard *et al*., 2016; Sedlacek *et al*., 2016). The forms of pollution occurring around the marine ecosystems found in these communities can also

impact nutrient levels and aid the persistence of microbial pathogens. Some of these microbial pathogens are notorious bacteria species that have been implicated in diarrhoea.

Diarrhoea is one of the top ten causes of illness and mortality in Ghana, as it is in other low-income nations (Troeger, 2017). Studies have also shown that nine out of ten people who contracted the illness were as a result of environmental factors which makes its role in the transmission of diarrhoea, key (Ghana News Agency, 2023). Despite the poor aesthetic outlook of the coastal marine ecosystems within the study communities, they depend on it for recreation, harvesting of biota, therapy for infected skin and even as recreational therapy. This reflects their ill-informed perceptions and knowledge about the potential of polluted aquatic ecosystems to be diarrhoea transmission pathways within these communities. It also implies that interaction with surrounding marine ecosystems in these communities is inevitable. The dependence of the communities on coastal landscapes for their ecosystem services makes their well-being and sustainability a function of the status of the ecosystems. If the aquatic ecosystems are heavily polluted, the biophysical and chemical parameters are elevated (proxy indicators of pollution and marine health status) and they can become surrogates for high loads of diarrhoea pathogens. They may also automatically become pathways for diarrhoea transmission. The resulting poor aquatic health status can then impact the ecosystem services and by extension the health of the community which largely depends on these services.

1.3 Research questions

Having identified diarrhoea as a potential health hazard the selected coastal communities for this study may be exposed to, the following questions were derived to investigate components of the surrounding coastal marine ecosystems as potential pathways for diarrhoea transmission.

1. Are the components (seawater, biota, and sediment) of the coastal aquatic ecosystems hosts of significant amounts of diarrhoeagenic and indicator bacteria?
2. Are there biophysical and physicochemical properties that correlate with and facilitate the presence of these diarrhoea pathogenic and indicator bacteria?
3. What is the spatio-temporal distribution of diarrhoeagenic and indicator bacteria present in the aquatic ecosystem components?
4. What are the perceptions of coastal community residents on the components of the aquatic ecosystems being potential pathways for diarrhoea transmission and contraction?

1.4 General objective

This study sought to assess the aquatic ecosystem health status of selected coastal communities and the possibility of their components (water, sediment, fauna) being diarrhoea transmission pathways.

1.5 Specific objectives

The specific objectives of this study were to;

1. Measure the levels of physicochemical parameters used as proxy indicators of water pollution.

2. Measure the levels of indicator and diarrhoeagenic bacteria present in water, biota, and sediments.

3. Assess microbiologically the health status of the coastal aquatic ecosystems.

4. Examine the correlations between the measured physicochemical parameters and the levels of diarrhoeagenic and indicator bacteria.

5. Ascertain the perceptions of residents within the selected coastal communities on the potential risk of diarrhoea contraction through their interactions with the surrounding aquatic ecosystems.

1.6 Justification

Components of the coastal aquatic ecosystems such as biota, sediment, and seawater are gradually becoming hosts to diarrhoeagenic bacteria (WHO, 2003; Fernández-Delgado & Suarez, 2009; Mulamattathil *et al.*, 2014; Hassard et al., 2016; Sedlacek *et al.*, 2016; Akita *et al.*, 2020; Akita *et al.*, 2021). This is so because of the discharge of untreated sewage or treated sewage effluent; run-off from adjacent land areas, recreational use, stormwater drains, industrial effluents; and faecal inputs from wild animals in these ecosystems. They are all sources of a wide range of pollutants including microbial pathogens in freshwaters and coastal waters (Florini *et al.*, 2020). These have influenced the presence of microbial contaminants within coastal aquatic ecosystems in Ghana and have implications for human health and sustainability (Akita *et al.*, 2021). It is therefore prudent to investigate the coastal aquatic ecosystems as possible routes through which diarrhoea could be transmitted and contracted. Interaction with and dependence on these ecosystems despite their poor aesthetic outlook and possibly highly polluted components is inevitable. It is also necessary to

understand the perceptions of the communities about their sanitary practices that contribute to the poor status of the water bodies and by extension the presence of diarrhoea transmission pathways. These will furnish public health practitioners and coastal management policy with research-based knowledge on diarrhoea and additional transmission routes within the coastal aquatic ecosystems. Furthermore, data from the mechanistic and holistic approach to this research will be an education base for communities on ecosystem health, associated health risks, and their role in sustaining marine ecosystems and their well-being. These measures are necessary to tick the indices required to attain Sustainable Development Goal 3 (Ensuring Healthy Lives and Promoting Well-Being for All at All Ages), Sustainable Development Goal 6 (Ensuring Availability and Sustainable Management of Water and Sanitation for All), and Sustainable Development Goal 14 (Life Below Water: 14.1 Reduce Marine Pollution (United Nations, 2016).

1.7 Structure of the thesis

The thesis report for this study is structured as follows;

- Chapter 1 is a general overview of the research as well as the goals and the essence of the research.
- Chapter 2 is a review of related articles and literature on the thesis area.
- Chapter 3 describes the methodology of the study. It encapsulates the description of the study sites, the sampling procedures for the coastal aquatic components examined and the human population whose perceptions were sought, laboratory analyses, and the necessary statistical tools and procedures used to analyze the findings.
- Chapter 4 is a presentation of the data gathered following sampling and the analysis carried out on them.

- Chapter 5 is the thesis discussion which encapsulates the interpretations, relationships and possible implications drawn out from the findings while comparing them to findings from other closely related research.
- Chapter 6 gives the overall conclusion of the study, emphasizing the major findings, deductions as well as recommendations for further studies.

CHAPTER TWO

2.0 LITERATURE REVIEW

Diarrhoea, a leading cause of morbidity and mortality worldwide, is associated with contaminated water sources and food consumption. As such, understanding the potential pathways through which diarrhoeal causative agents can spread is essential for assessing and mitigating the risks they pose to human populations. This literature review aims to explore the current state of knowledge regarding the link between marine ecosystem health and the transmission of diarrhoeal diseases, shedding light on the various factors and mechanisms that contribute to this intricate relationship. By synthesizing and analyzing the existing research, this review also provides valuable insights into the potential implications for public health and marine conservation efforts.

2.1 Ecosystems

An ecosystem is an organization of activities within a geographical area that involves the living or biotic components (animals, and microorganisms) and the non-living or abiotic (rocks, soil, minerals, water bodies, atmospheric conditions, etc.,) components of different kinds interacting with each other and their environments. These interactions ensure the continuity and sustainability of the environments and their inhabitants. It also connotes that biological and natural communities of varied populations of organisms reside together in these environments operating based on their natural and adapted competencies and also operate together systematically to ensure their survival and optimal productivity. (NationalGeographicSociety, 2011). For these interactions

and the expected functions to take place, these ecosystems must exist in a state of optimal health (Corvalan *et al*., 2005; Myers *et al.*, 2013).

Modern classifications of ecosystems present beyond the known divisions of ecosystems, such as terrestrial and aquatic to other sub-classifications such as Agro, Coastal, Forest, Freshwater systems, and Grassland ecosystems all covering about 90% of the surface area of land on earth (Burke *et al*., 2001). Humans get a wide range of goods and services (ecosystem services) from these ecosystems. They include food, materials for building and clothing, medication, climate regulation, water purification, nutrient cycling, leisure activities, and amenity value. The products and services that come from ecosystems are the foundation of all global economies, hence they are termed life-support systems for human well-being and all other forms of life (Corvalan *et al*., 2005; Myers *et al.*, 2013; Burke *et al*., 2014).

2.2 Coastal ecosystems

Coastal ecosystems are special environments of confluence between land and the ocean consisting of plants and other animals that can adapt to saltwater or saline conditions and tidal changes. These environments by implication are often inundated by sea or salt water. They encompass the immediate surrounding lands as well as the intertidal and subtidal regions on and above the continental shelf (up to a depth of roughly 200 meters). (Burke *et al*., 2001; MIT, 2021). Coastal regions are home to a wide variety of ecological and food production systems, such as freshwater and brackish water wetlands, mangrove forests, estuaries, marshes, lagoons, salt ponds, rocky or muddy intertidal areas, beaches, dunes, coral reef systems, seagrass meadows, and kelp forests. They also contain nearshore islands, semi-closed areas, and nearshore

coastal waters of the continental shelf. These coastal systems are dynamic and extremely productive, and many of them are currently undergoing more rapid changes than at any other point in their history (Béné *et al*., 2012).

2.3 Coastal ecosystems' significance globally and within Ghana

Despite making up less than 5% of the total land area on earth, the narrow band of coastal lands and islands are vital to the over two billion people who live within 100 kilometres of the coast. Currently, 50 kilometres from the coast is where you can find half of the world's major cities (those with more than 500,000 inhabitants). Population densities on the coast have over time become over three times higher than those inland (Kay & Alder, 2017).

Coastal ecosystems located around continental edges are regions with exceptional biological production and ease of access. They have been hubs for human activities for centuries and have become principal providers of fish, shellfish, and seaweed for both human and animal sustenance. They also serve the purpose of being significant sources of fertilizer, medicines, cosmetics, and domestic products. Their unique aesthetic appearance and qualities make their environment, sites to be naturally drawn to by the world's population.

Coastal ecosystems, which include a wide variety of habitat types and are home to numerous species and genetic varieties, store and cycle nutrients, filter pollutants from inland freshwater systems, and aid in the protection of shorelines from erosion and storms. On the opposite side of shorelines, seas provide a significant source of oxygen and a large carbon sink due to the high productivity of phytoplankton. They also play a

significant role in controlling world hydrology and climate (Burke *et al*., 2001; Béné *et al*., 2012).

Coastal areas by their geographical locations differ in terms of resources, plant and organism diversity, health statuses, the nature of the impact of natural and anthropogenic activities on them, and how resilient they are. West African coastal systems are a crucial part of the African Ecosystem and are rich in biodiversity and natural resources, producing ecosystem services that account for around 57% of its gross domestic product (GDP) (WA BiCC, 2021). They serve as centres of increased economic activity with a huge chunk of the human population living in and depending on these ecosystems. The area is also known from evidence, to be highly sensitive to the climate change impacts resulting from sea level rise that leads to coastal erosion, flooding, and submergence (IPCC, 2014). Mangroves, another component of the coastal aquatic ecosystems, are intricate, one-of-a-kind, and extraordinarily productive ecosystems that are typically found in tropical and subtropical intertidal areas of the world. According to Singh (2012), mangrove habitats are crucial in terms of biodiversity because they supply fish, birds, crabs, and other marine species, with food, shelter, and places to raise their young. They also serve as sinks and filters for a vast amount of pollutants and contaminants (Walter *et al*., 2009).

A quarter of Ghana's population lives in the coastal zone, and policy documents including the Ghana Shared Growth and Development Agenda, the National Climate Change Policy, and the National Environmental Policy have all emphasized how important this area is (Lawson, 2015). Ghana’s coastal zones are known for their rich and diverse production capabilities. They are hosts to features such as fisheries and

other plant and animal biodiversity including wetlands and mangroves, oil and gas, lagoons and estuaries, sandy and rocky beaches, historical monuments, ports, and harbours (Yaqub, 2017). It has also been estimated that almost three-quarters of the country's industry and nearly a quarter of its population are situated along the shoreline. Most of Ghana's coastal communities are long-term indigenous settlements, some of which date back hundreds of years. In these communities, the settlers make a permanent home and a living. Private property ownership has increased recently and additionally, local and international developers have purchased land along the coast for residential and commercial interests (Oteng-Ababio *et al*., 2011; Government of Ghana, 2013). Along Ghana's coastline, there are numerous hotels, fishing ports, and two bustling cities, Tema and Takoradi (Akita *et al*., 2021). Ghana's coastal resources also provide coastal communities with access to a variety of recreational, educational, therapeutic, social and economic benefits (Akita *et al*., 2021).

2.4 The concept of ecosystems' health and its implications for the coastal landscapes

An ecosystem will generally be described as a healthy one if it is resilient in the face of external disturbances and can continuously function optimally in its ability to provide goods and services necessary for human survival and satisfaction for surrounding societies (Müller *et al*., 2020). The inception of the concept of ecosystem health dates back to the 18th century and has constantly evolved. (Müller *et al.*, 2020). Its evolution has also involved taking into consideration human and societal perceptions in defining it and the kind of indicators that may be applied in assessing it (Lu *et al.*, 2015; Müller *et al.*, 2020). Applicable to all complex ecosystem types, Constanza (1992) defines ecosystem health as the state of any complex ecosystem where it is healthy and free

from any form of "distress syndrome" because of how stable and sustainable it is. This means the ecosystem is actively functional, has its structure intact, can independently exist and be of significant service over time, and is resilient to stresses and strains (Rapport *et al*., 1999; Lawson, 2014; Wardel, 2020). It would also have healthy organisms and communities, as well as enough functional varieties (Tett *et al.*, 2013). It can therefore be implied that a healthy coastal aquatic ecosystem in its functioning not only provides services to humans but ensures continuity over time. In general, they can maintain biological and social functions that help humanity realize sustainable goals for survival. Also, in studying stress ecology, the health of that ecosystem will be defined or measured in terms of its vigour (strong and robust), how organized its functions are, the absence of distresses (natural and anthropogenic disturbances), and how resilient that ecosystem is in the face of these disturbances (Rapport *et al*., 1999; Lawson, 2014; Wardel, 2020).

Coastal ecosystems especially in tropical countries of West Africa are more vulnerable to the impact of climate change (tidal wave action, storm surges, and floods) in combination with anthropogenic activities (Mclver *et al*., 2016; World Bank, 2020). Among the common challenges faced by Ghana's coastal communities, climate change and anthropogenic activities or interventions like overexploitation of natural resources, marine and coastal pollution, illegal sand mining, rapid urbanization, and unsustainable land use supersede them all in terms of their effects (World Bank, 2020). These effects include but are not limited to coastal erosion and flooding, landslides, rising sea levels and temperatures, loss of biodiversity and ecosystem services, severe weather, widespread degradation of ecosystems, and the proliferation of invasive species (WA

BiCC, 2021; World Bank, 2020). These issues degrade the coast, endanger ecosystems, jeopardize human livelihoods and well-being, erode productive capacity, and upsurge vulnerability to natural disasters and diseases (World Bank, 2020). These challenges also evidently affect the robustness and resilience of a healthy ecosystem. In extension, coastal communities' health and livelihood are also affected (WA BiCC, 2021).

A variety of mechanisms, including direct discharge into water bodies, runoff from the land, atmospheric deposition, and ocean circulation, result in the widespread dispersion of many contaminants and their entry into coastal waters. The build-up of persistent chemical contaminants in marine species can result in high rates of mortality or illness, which can upset the ecosystem's delicate equilibrium. Fish and shellfish that have been contaminated are no longer safe to eat. High levels of pathogens in the water column can also result in the closure of shellfish beds and beaches, which can have a significant negative economic impact. They can also pose health risks to people. Industrial and domestic sewage, agricultural runoff, sediment pollution, oil discharges, and spills, and solid waste from domestic, commercial, and marine sources are all examples of pollution sources (Burke *et al.*, 2001). The assessment of ecosystem health must therefore take into account not just ecological factors but also social, economic, and cultural factors and their impacts as well (Müller *et al.*, 2020).

2.5 Assessment of ecosystems' health

The physiological health of the constituent organisms; the distinctive traits and interactions of the species present; and the emergent qualities of the system comprising the biota and their surroundings all contribute to ecosystem health. They are robust, resistant to externally imposed constraints, and capable of surviving

without human intervention. The sustenance of human activities is also a function of healthy ecosystems (Tett *et al.*, 2013). Elliott (2011), in examining the concept of health, outlined six biological organisational levels: cell, tissue, organism, population, community, and ecosystem, each of which might be categorised as healthy or unhealthy. At the level of organisms, the definition of "health" appears clear-cut and identical to that of physical well-being for humans. Health is also concerned with the survival of populations or species. The concept becomes more difficult when examined at the level of communities and ecosystems. Based on a review by Müller *et al*. (2020), it was established that ecosystem health indicators are dependent on the structure and function at different locations and at different times. A keen look at established ecosystem health indicators like species diversity and water quality reveals the unhealthy state of many ecosystems on our planet. This can lead to the impairment of functions of these ecosystems and by extension, the life-sustaining services they render to man. Evaluating ecosystem health requires the analysis of indicators that are well grounded in principles of ecology and the theory of systems in place. Some of these broadly applied indicators are not only holistic but also integrate a broad range of information on the environment. They include the abundance of selected species, the concentration of selected elements, correlations between different classes of organisms or elements, ecological strategies or processes, ecosystem composition and structure, and correlations between different classes of organisms or elements. Adapted for this study was the approach developed by Tett *et al.'s* (2013) review of ecosystem health assessment that drew on existing models and approaches to ill-health diagnostics to develop empirical and aggregatable criteria for determining ecosystem health (Table 2.1). This approach looks at various generic components of marine ecosystems in an

undisturbed state against norms that should exist within the ecosystems while interacting. It also took into account water framework directives that qualify its quality level, pollutants and contaminant levels that do not disturb the normal flow of interactions or give rise to pollution effects.

Table 2.1 Components of (good) ecosystem health, according to the empirical approach, and as interpreted by EU Directives.

Generic component of ecosystem health	Ecological norm	WFD 'high-quality status'	MSFD 'qualitative descriptors'
Individual organisms are healthy and reproductively fit, not showing widespread pathologies, nor substantially contaminated with pollutants, nor exhibiting reduced resistance to disease or stress or reduced ability to detoxify	Body burden of contaminants below defined threshold; no substantial differences in performance compared with individuals at unpolluted station	Pollutant concentrations 'remain within the range normally associated with undisturbed conditions'.	Concentrations of contaminants are at levels not giving rise to pollution effects.'

Column 3 gives corresponding specifications from Annex V of the EU Water Framework Directive (WFD) for 'high-quality status' (which we equate with good health) in 'transitional' and 'coastal' waters. Column 4 refers to the relevant 'qualitative descriptors for determining good environmental status' in Annex I of the Marine Strategy Framework Directive (MSFD), which are expanded by the European Commission (2010)

This study measured and determined the health status of the coastal aquatic ecosystems using indicators, and the concentration of selected elements. The selected elements and

indicators measured were biophysical, chemical and microbiological parameters that help determine the level of impact of anthropogenic activities that affect the environment. First, important indicators that are required for the assessment were identified. Next, the indicators are measured directly compared to standards and finally, the ecosystem's health was evaluated based on the results of the comparisons.

2.6 Diarrhoea

The passage of three or more loose or liquid stools per day is referred to as diarrhoea. It is typically a symptom of an infection of the gastrointestinal tract caused by a variety of bacterial, viral, and parasitic organisms. Diarrhoea is spread through contaminated food or drinking water, person-to-person contact, and poor hygiene. Infection is more common when there is a lack of adequate sanitation and hygiene, as well as safe drinking, cooking, and cleaning water (WHO, 2017). Currently, it is estimated that 842,000 children die each year from diarrhoeal diseases brought on by poor access to drinking water, sanitation, and hand hygiene, with Sub-Saharan Africa and South-East Asia experiencing the highest death rates (Pruss-Ustun *et al*., 2014). They frequently also cause malnutrition, which can have long-lasting impacts on adult development, stunted growth, and impaired cognitive development (Guerrant *et al*., 2012).

Diseases and conditions whose effects are influenced by climate change like heat, malnutrition, malaria and diarrheal diseases according to the 2022 IPCC report, are projected to cause an additional 250,000 deaths per year by 2050. More than half of this mortality is predicted for Africa (Cissé *et al*., 2022). Diarrhoea is responsible for around 22% of all child mortality in underdeveloped nations (Anyorikeya *et al.*, 2016). In Sub-Saharan Africa, diarrheal illnesses are a major cause of infant mortality and morbidity

and climate variability has been predicted to make them more likely to occur (Kemajou, 2022). In 2017, A WHO report stated that more than a quarter (26.7%) of global diarrheal fatalities were found among children under five years old with 90% of those diarrheal deaths occurring in South Asia and sub-Saharan Africa. It has been reported to be prevalent in Ghana, with a one-time record of 113,786 cases in children and 354 fatalities in 2011 (Anyorikeya *et al.*, 2016).

2.7 Coastal ecosystems health and diarrhoea transmission: the nexus

Despite the significance of these unofficial water sources (coastal waters) (Emma *et al*., 2015), the majority of current work on diarrhoea transmission pathways in the tropics tends to concentrate on drinking water supplies (wells, boreholes, etc.) while ignoring the broader environment (Opisa *et al*., 2012; Bain *et al*., 2014). Overtime there has been evidence of a link between the variable climatic factors (rainfall, temperature, etc.) and the incidence of several disease pathogens, with the impacts and risks of exposure being exacerbated by developments around the coast, population growth, and land-use change (IPCC, 2014; Hussain *et al*., 2019). A variety of mechanisms, including direct discharge into water bodies, runoff from the land, atmospheric deposition, and ocean circulation, results in the widespread dispersion of many contaminants and their entry into coastal waters. The build-up of persistent chemical contaminants in marine species can result in high rates of mortality or illness, which can upset the ecosystem's delicate equilibrium. Fish and shellfish that have been contaminated are no longer safe to eat. High levels of pathogens in the water column can result in human health risks as well as beach and shellfish bed closures, both of which can have significant negative economic effects (Burke *et al*., 2001).

The majority of illnesses contracted when swimming are thought to be caused by exposure to microbial pathogens, which enter the water from point sources such as raw sewage. Non-point sources, such as stormwater runoff, resuspended sand, animal faeces, and human waste, may also influence the water quality of coastal recreational waters (Elmir *et al.* 2007).

Marine coastal zones utilized for recreation, particularly those close to very polluted areas, pose a major ecological and public health risk due to microbial contamination. Human activities are thought to be able to speed up the pace of nutrient absorption into aquatic ecosystems. Surface runoff and improperly handled residential, industrial, and municipal wastes that are dumped into the sea may promote the intensive growth of microplankton or serve as a source of pathogenic microorganisms (Fleisher *et al*., 1993). Discharges of untreated sewage or sewage effluent; run-off from adjacent land areas, recreational use, stormwater drains, industrial effluents; and faecal inputs from wild animals are all sources of microbial contaminants found in freshwaters and coastal waters (Florini *et al*., 2020).

These factors are a combination of anthropogenic and climatic factors that could lead to the introduction of pathogenic diarrhoeal bacteria among other microbial contaminants that are responsible for diarrhoea. These pathogens when introduced into coastal and fresh waters can be lodged either in the water bodies themselves, the sediments or in the aquatic fauna found in these water bodies, most of which are agriculturally significant species (WHO, 2003; Fernández-Delgado & Suarez, 2009; Mulamattathil *et al*., 2014; Hassard *et al*., 2016; Sedlacek *et al*., 2016). These three components of coastal aquatic ecosystems are those with which direct contact cannot

be avoided making them possible pathways and vectors through which humans can encounter diarrhoeal pathogens and consequently contract diarhoea the disease condition.

Waterborne gastrointestinal infections like diarrhoea are predicted to become more prevalent due to global climate change, particularly in impoverished and vulnerable areas. This is because these regions are challenged with little adaptation potential including insufficient access to clean water and sanitation, poor dietary habits, lack of hygiene practices, and a lack of healthcare access, which are influenced by current environmental and socioeconomic problems. The relative risks of diarrhoea are expected to rise by 8–11% (2010–2039) and 22–29% by the end of the century in the wake of climate change (Kolstad & Johansson, 2011; Mellor *et al*., 2016). However, because there are numerous interconnected components, including mediating drivers like ecological disturbance, biodiversity loss, and social and economic situations, the relationship between climate change and health is complicated. Transdisciplinary-based techniques are therefore necessary to integrate computational models with actual data on the numerous causes affecting diarrhoea to evaluate the risk of diarrhoea and improve its treatment in several climate scenarios (Mellor *et al*., 2016). Due to the rising trend of diarrhoea cases in Ghana, the Ministry of Health has recently expanded its educational campaign on the prevention of diarrhoeal sickness (Mumuni, 2013). It is also crucial to understand the variables that regulate the dispersion of water-borne pathogens and their corresponding indicators given the large numbers of fatalities and the crippling nature of diarrhoea brought on by interactions with supposedly contaminated water.

Waterbodies, especially the coastal seas and the Great Lakes, are the first line of defence against a variety of natural and man-made threats and calamities. These challenges affect the robustness and resilience of their health. In extension, coastal communities' health and livelihood are also affected. They are a major source of food, employment, recreation, and housing. To ensure social sustainability and well-being it is crucial to keep these ecosystems functioning and healthy (Shuval, 2006; WA BiCC, 2021).

2.8 Diarrhoea and diarrhoeagenic bacteria commonly implicated with the disease in coastal environments

This research will be narrowed down to the investigation of diarrhoea of pathological origins with a focus on those caused by gastrointestinal pathogenic bacteria and indicator bacteria. Bacterial diarrhoea is particularly a more serious form of diarrhoeal syndrome with more severe symptoms. Understanding this cause of diarrhoea and distinguishing it from other less serious causes of diarrhoea is therefore crucial (DuPont, 2014). Acute diarrhoea brought on by bacteria might take more severe forms like dysentery. Dysentery is a more severe illness and is defined as diarrhoea accompanied by blood (plus or minus mucus). *Escherichia coli*, Shigella, Salmonella, Campylobacter (most common in children), Yersinia, and Clostridium spp. are the most often found pathogens that cause bacterial diarrhoea. Shiga-producing *Escherichia coli* (STEC), Shigella, Salmonella, *Entamoeba histolytica*, Giardia, Cryptosporidium, Cyclospora, and enteric viruses can all cause traveller's diarrhoea (Akhondi & Simonsen, 2022). These organisms have also been identified as causal agents of enteropathogenic diseases like diarrhoea associated with faecal contamination in

coastal waters (Metcalf, 1978; Grimes 1991; Bosch *et al*., 2001; Kong *et al*., 2002; Rothenheber, 2017).

The "five Fs"- fluids (water), fingers (hands), food, fields (dirt), and flies—have historically been thought of as the "five environmental channels" by which gastrointestinal diseases are spread (Eisenberg *et al*., 2007). Low-income nations have evaluated the presence of faecal indicator bacteria and a few enteric pathogens in source water, ambient waters, stored drinking water, on the hands of children and caregivers, stored food, soil, and flies. (Julian, 2016; Sclar, 2016). Some investigations that employed cross-sectional relationships between faecal contamination levels in the environment and the prevalence of concomitant diarrhoea showed indeed there is a relationship between them (Wright *et al*., 2004; Gruber *et al*., 2014). Anthropogenic and industrial influences also have an impact on mangroves. Despite extensive research on mangroves, little is known about the diseases that could have an impact on public health even though instances of illnesses connected to the ingestion of foods connected with mangroves have elevated (Poharkar *et al*., 2016). In a study conducted by Phoarkar *et al*. (2016) in India, mangrove swamp components such as the water, sediments and biota were sampled. According to the microbiological analysis's findings, the total viable counts of pathogens such as *E. coli*, Listeria, Salmonella, and Vibrio spp. ranged from 1.25 to 3.93 * 10^3 CFU/ mL, above the necessary thresholds. Counts of salmonella were in the greatest range of 3.1-3.93 * 10^3 CFU/ml and had a 40% frequency. Considering the pathogenicity and high occurrence of Salmonella spp, molecular studies were further carried out. The polymerase found the invA gene in 35% of the Salmonella isolates chain response (PCR). The results indicated that pathogens adapted

to this habitat, causing the local biota found there to become contaminated. These findings also necessitate a need to investigate these mangrove ecosystems among other coastal marine ecosystems that are also susceptible to pollution.

2.9 Commonly implicated diarrhoeagenic and indicator bacteria targeted for the study.

2.9.1 *Escherichia coli* (*E. coli*)

This microorganism is a Gram-negative, rod-shaped, bacilli with rounded ends and normally measures up to 2.0 to 6.0mm in length and 1.1 to 1.5mm in width (Percival & Williams, 2013a; Desmarchelier & Fegan, 2016). The majority of *Escherichia coli* strains are non-pathogenic commensals, and they are typically found in the gastrointestinal tracts of humans and other vertebrates. However, there are several *E. coli* types that are pathogenic and can cause several illnesses, some of which are fatal. The most significant *E. coli* strains in terms of food safety are those that produce diarrheal illnesses (Percival & Williams, 2013a). There are at least six main diarrheagenic pathovars of *E. coli*, and each type combines an initial attachment to the host cell with a subsequent adverse effect (Croxen & Finlay, 2010). Faecal-oral infection is spread mostly through tainted food and drink. Direct contact with an infected individual or contaminated food or water are the two main ways that humans become infected. Ground beef, contact with animals in public settings (petting zoos), polluted apple cider, and contaminated water in recreational areas have all been connected to outbreaks. The majority of *E coli* strains require 10 hours to 6 days of incubation (Makvana & Krilov, 2015). There are several different strains of diarrheagenic *E. coli*. Each particular variety has a unique mechanism for causing diarrhoeal sickness, and each disease has a unique set of clinical signs (Percival & Williams, 2013a).

Table 2.2 Classification of *Escherichia coli* associated with diarrhoea

Pathotype	Epidemiology	Type of Diarrhoea
Shiga toxin-producing *E. coli*	Hemorrhagic colitis and hemolytic uremic syndrome in all ages	Bloody or non-bloody
Enteropathogenic *E. coli*	Acute and chronic endemic and epidemic diarrhoea in infants	Watery
Enterotoxigenic *E. coli*	Infant diarrhoea in resource-limited countries and traveller's diarrhoea in all ages	Watery
Enteroinvasive *E. coli*	Diarrhoea with fever in all ages	Bloody or non-bloody; dysentery
Enteroaggregative *E. coli*	Acute and chronic diarrhoea in all ages	Watery, occasionally bloody

The survival and multiplication of *E. coli* in the environment have made it a useful bacterium to indicate faecal pollution and has become a widely employed faecal indicator bacterium (FIB) for evaluating water quality (Jang *et al.*, 2017). It has been demonstrated that *E. coli* levels in recreational water affected by recognised pollutant sources (such as sewage) are correlated with gastrointestinal sickness occurrences (USEPA 1986; Edberg *et al.*, 2000). As a result, E. coli is used as a marker of faecal contamination in samples of recreational water based on the Ambient Water Quality Criteria for Bacteria of the U.S. Environmental Protection Agency recommendations (USEPA 1986).

2.9.2 Salmonella

Salmonella species are bacillus-shaped, Gram-negative, facultatively anaerobic, non-spore-forming microorganisms. They are typically 2 to 5 mm long and 0.8 to 1.5 mm broad. A key factor in identifying Salmonella is motility, which is facilitated by peritrichous flagella. However, numerous non-motile strains have been discovered in

clinical settings. The Salmonella organism group are a group of extremely harmful organisms that infect a wide range of hosts. Most commonly, enteritis and "typhoid-like" illnesses are caused by salmonella. Salmonellosis can present in individuals in three clinically distinct ways: gastroenteritis, enteric fever, and septicaemia. Gastroenteritis often develops 18–48 hours following Salmonella exposure. The paratyphoid bacilli, *Salmonella paratyphi* A, B, and C, are the most common causes of enteric fever. Compared to paratyphoid fever, enteric fever from *Salmonella typhi* lasts longer and has a greater fatality rate. Consistent fever, diarrhoea, and abdominal pain are signs of the condition, which can also cause deadly liver, spleen, pulmonary, and brain damage (Percival & Williams, 2013b). Environmental samples from aquatic and marine areas typically include Salmonella (Baudart *et al.*, 2000; Catalao *et al.*, 2000; Heinitz *et al.*, 2000; Martinez-Urtaza *et al.*, 2003). Coastal watercourses absorb water directly from rivers, which can bring enteric bacteria from their natural reservoirs inland, in addition to waste from human and industrial activity (Baudart *et al.*, 2000; Martinez-Urtaza *et al.*, 2003). Another source of pollution to aquatic fauna in coastal habitats is intestinal bacteria found in marine components. Quite a number of them are ingested by people unprocessed, which raises the possibility that they may serve as disease transmission vehicles and endanger public health (Martinez-Urtaza *et al.*, 2004).

2.9.3 Shigella

Shigellae are rod-shaped, Gram-negative, non-motile bacteria and belong to the family Enterobacteriaceae (Percival & Williams, 2013c). Shigella species can cause shigellosis, a type of bacterial diarrhoea. It is widespread in developing nations and spreads through direct person-to-person contact, consuming tainted or food prepared in

poor sanitary conditions. All age groups are susceptible, but the very young, the elderly, and those with impaired immune systems are at higher risk. Shigella is comparatively resistant to stomach acid, and only a few numbers of organisms are needed to spread the illness. After being consumed, it grows in the small intestine before moving on to the colon, where it generates the shigella enterotoxins and serotype toxin 1, which can result in bloody or watery diarrhoea. Clinical symptoms often appear between 12 hours and 3 days after the organism has been consumed, with an average incubation time of 3 days. High fever, vomiting, diffuse colicky stomach discomfort that is followed by bloody mucoid diarrhoea, and tenesmus are among the symptoms. Within 5 to 7 days of the first symptoms' emergence, the illness typically cures on its own. The extremely young, the elderly, and those with compromised immune systems, however, may experience problems or even pass away from this illness (Aslam & Okafor 2022). Infections that result from shigella are often passed from person to person through contaminated food, contaminated water, or direct contact (Kato *et al.*, 2020). Marine environments have been implicated in the spread as well. The occurrence of shigella is more often in instances where poor water quality was detected with *Shigella flexneri* being the most implicated with waterborne illnesses and fatalities (Subekti *et al.*, 2001; Zahara *et al.*, 2022). The occurrence of Shigella species that are resistant to antibiotics has also been associated with inflow from surface waters such as rivers and estuaries.

2.9.4 Vibrio species

Vibrios are gram-negative, highly motile, facultative anaerobes (those whose survival does not solely require oxygen) with one to three whiplike flagella at one end. Their cells are curved rods, 0.5 m (mi wide and 1.5 to 3.0 m long. Vibrios are a leading source of human food-borne disease related to seafood intake globally, as well as contaminated

food and drinking water in developing countries. *Vibrio cholerae, Vibrio parahaemolyticus, Vibrio vulnificus*, and other vibrios cause clinical syndromes ranging from mild, self-limiting gastroenteritis to life-threatening primary septicemia. These bacteria, as natural occupants of the aquatic environment, constitute a constant danger to food safety. *V. cholerae* causes cholera, while *V. parahaemolyticus* and *V. vulnificus* all cause acute enteritis also known as bacterial diarrhoea and are the most commonly implicated in diarrhoeal diseases globally (Powell 1999; Britannica 2019).

Table 2.3 Most important vibrio species, their sources, and clinical significance (Baker-Austin et al., 2018)

Species	Source of Infection		Route of Infection	Clinical Manifestations Associated with Diarrhoea
	Seafood	Sea water	Oral	
V. cholerae	Yes	Yes	Yes	Gastroenteritis
V. parahaemolyticus	Yes	Rarely	Yes	Gastroenteritis
V. vulnificus	Yes	Yes	Yes	Gastroenteritis
V. fluvialis	No	Yes	Yes	Gastroenteritis
V. hollisae	Yes	Yes	Yes	Gastroenteritis
V. mimicus	Rarely	Yes	Yes	Gastroenteritis
V. metschnikovii	No	Yes	Probably	Gastroenteritis

2.9.5 Indicator bacteria

In this study, the two indicator bacteria selected for this study were *Escherichia coli* and Enterococcus species. These microorganisms are also known as faecal indicator organisms. *E. coli* was enumerated, isolated, and identified while *Enterococcus spp.* was isolated and identified. When found in recreational water, indicator microorganisms often aid in estimating the health risk of individuals who interact with these recreational waters (Wade *et al.*, 2003). Certain strains of *E. coli* and Enterococcus have also been classified as being enteropathogenic even though they serve as indicator bacteria. Hence their presence also implies that other pathogenic

bacteria and or microorganisms are present, faecal contamination is occurring and there is a potential for sewage pollution within those water bodies. This is because they are commonly found in the gut and faeces of warm-blooded animals and can survive externally and in the environment for prolonged periods (EPA, 2012; Guillaud *et al*., 1997; Health Canada, 2012; Medema *et al*., 2003; Lleo *et al*., 2005 Garcia-Migura *et al*., 2007; Leavis *et al*., 2007; Stewart *et al*., 2008; Palmer *et al*., 2010; Korajkic *et al*., 2018). These two bacteria are also recommended by the World Health Organisation and the United States Environmental Protection Agency (US EPA) as key indicator organisms for assessing microbiologically the water quality and potential presence of pathogens within coastal waters (US EPA, 2012; WHO, 2021).

2.10 Physicochemical indicators of water quality and their relationship with microbial pathogens in coastal waters

Many human illnesses, including cholera, typhoid fever, dysentery, and gastroenteritis, are often brought on by bacteria from infected people's faeces that contaminate food and water that is consumed by healthy individuals. The conventional and common microbiological markers of water quality are coliform bacteria (Armah 2014). A lot of research carried out on aquatic ecosystems has shown relationships between physicochemical parameters which also serve as proxy indicators of water pollution and the presence of coliforms in the water (Javed *et al*., 2014; Vincent-Akpu & Yanadi, 2014; Hassard *et al*., 2016; Karbasdehi *et al*., 2017; Roll and Fujioka, 2018; Akita *et al*., 2020; Akita *et al*., 2021; Kambire *et al*., 2022). Some of these physicochemical parameters include;

Temperature

Temperature refers to the measure of heat energy in a given environment. Monitoring temperature is essential for assessing water quality and pollution impacts in marine ecosystems. Anthropogenic activities can lead to temperature changes that affect microbial communities and overall ecosystem health. Discharge of heated effluents from industrial processes or power plants can increase water temperature; Urban areas can experience the urban heat island effect, raising local temperatures due to human activities, buildings, and reduced vegetation cover, which can influence nearby water temperatures; Temperature alterations can influence microbial growth rates, ecosystem interactions, and the prevalence of harmful microorganisms. Temperature affects the solubility of oxygen in water where warmer waters can hold less dissolved oxygen, potentially leading to lower oxygen levels. Therefore, temperature serves as a crucial physicochemical proxy indicator for evaluating both anthropogenic and microbial pollution in marine environments.

pH (Acidity/Alkalinity)

pH is a measure of the acidity or alkalinity of a material, determined by the concentration of hydrogen ions present in the water. Anthropogenic inputs of pollutants and atmospheric emissions can alter pH, potentially disrupting microbial communities and overall ecosystem health. Industries may release acidic or alkaline pollutants into water bodies, altering pH levels and affecting the natural pH balance. Improperly treated or untreated wastewater discharges can introduce chemicals that alter pH, impacting water quality. Changes in pH can lead to stress on marine organisms and shift microbial dynamics, potentially favouring the growth of certain microbes over others.

Conductivity

Conductivity measures a material's ability to conduct electrical current, which is influenced by the concentration of ions (charged particles) present in the water. Industries, agriculture, and urban areas can introduce ions into water bodies through discharges, runoff, or wastewater, leading to increased conductivity. Saline Influx can contribute to elevated conductivity levels due to the introduction of saline or brackish water. Pollutants containing ions, such as road salts or industrial chemicals, can contribute to increased conductivity in runoff waters. Conductivity influences the availability of essential ions required for microbial growth and metabolism.

Overall high conductivity levels may indicate the presence of contaminants or altered water sources. Conductivity serves as a valuable physicochemical proxy indicator for evaluating both anthropogenic and microbial pollution in marine environments.

Salinity

Salinity refers to the concentration of dissolved salts in water, primarily composed of sodium chloride and other ions. Industrial and urban runoff can introduce pollutants that may alter the ionic composition of marine waters, impacting salinity. Different microbes have varying salinity tolerances. Changes in salinity can lead to shifts in microbial community composition and abundance. Salinity can also influence nutrient availability and transport, affecting microbial nutrient uptake and growth. High or low salinity levels may influence microbial growth and interactions, affecting ecosystem stability and function.

Total Dissolved Solids (TDS)

TDS refers to the concentration of all dissolved substances in water, including inorganic salts, minerals, and organic matter. High TDS levels may indicate the presence of

contaminants Industries can discharge pollutants containing dissolved solids into water bodies, increasing TDS levels. These pollutants may include chemicals, heavy metals, and other contaminants. Runoff from agricultural areas can carry fertilizers, pesticides, and other chemicals into water bodies, contributing to elevated TDS. Mining operations can introduce minerals and metals into aquatic systems, affecting TDS levels and water quality. TDS can also influence the transport of nutrients and other compounds that microbes rely on for growth and metabolism.

Dissolved Oxygen (DO)

Dissolved oxygen refers to the amount of oxygen gas dissolved in water. It is essential for the respiration of aquatic organisms and the functioning of aquatic ecosystems. Anthropogenic inputs of nutrients and organic matter can lead to reduced DO levels, disrupting microbial communities, promoting anaerobic conditions, and harming aquatic organisms. Low DO can also lead to hypoxia (low oxygen) or anoxia (absence of oxygen) conditions, which have severe ecological consequences. Excessive nutrient inputs from agricultural runoff or sewage can lead to algal blooms. After these blooms die and decompose, microbial respiration consumes oxygen, causing temporary oxygen depletion. Pollution from sewage discharges or industrial effluents introduces organic matter into water bodies. Microbes consume oxygen while breaking down this organic matter, potentially leading to oxygen depletion. Untreated or inadequately treated wastewater can contain high levels of organic and nutrient pollutants, contributing to reduced DO levels as microbes decompose these pollutants. The abundance of microbes that also respire aerobically results in the use of dissolved oxygen to break down organic matter or high oxygen consumption and lowered DO levels. Low DO conditions promote the growth of anaerobic microbes that do not require oxygen. These

microbes can produce byproducts like hydrogen sulfide, contributing to changes in water chemistry.

Biological Oxygen Demand (BOD)

BOD measures the amount of oxygen consumed by microorganisms during the decomposition of organic matter in water. BOD levels reflect the organic pollution load in marine ecosystems and its impact on microbial communities and oxygen availability. Untreated or inadequately treated sewage and wastewater contain organic matter that is decomposed by microbes, leading to high BOD levels. Industrial processes can release organic pollutants into water bodies, increasing BOD levels as microbes break down these substances. Runoff from agricultural areas can carry organic materials, such as manure and plant debris, into water bodies, contributing to elevated BOD. Elevated BOD levels also indicate increased microbial activity involved in decomposition due to the consumption of oxygen, leading to decreased dissolved oxygen levels. High BOD can result in oxygen depletion, creating hypoxic or anoxic conditions that impact aquatic life.

Nitrate (NO_3^-)

Nitrate is a chemical compound containing nitrogen and oxygen, commonly found in marine waters as dissolved nitrate ions (NO_3^-). Excessive nitrate can lead to detrimental effects on water quality, including eutrophication and harmful algal blooms. Anthropogenic inputs of nitrate can disrupt microbial community dynamics and nutrient cycling, impacting the overall health and balance of marine environments. Nitrate-rich fertilizers used in agriculture can leach into water bodies through runoff, leading to increased nitrate concentrations. This form of pollution is common in areas with intensive farming practices. Wastewater containing human and animal waste can

contribute significant amounts of nitrate to marine ecosystems, especially in areas with inadequate sewage treatment. Industries may release nitrogen-containing pollutants into water bodies, leading to elevated nitrate levels. Sources include chemical manufacturing, food processing, and industrial discharges. Excessive nitrate levels can contribute to eutrophication, a process in which nutrient enrichment stimulates excessive growth of algae and other microorganisms. This can lead to harmful algal blooms (HABs) and subsequent ecological imbalances. Elevated nitrate levels can influence denitrification rates and alter nitrogen cycling. Changes in nitrate levels can also influence the balance between ammonium and nitrate, affecting microbial community composition.

Sulfate (SO_4)

Sulfate is a common anion found in marine waters, primarily in the form of dissolved sulfate ions (SO_4^{2-}). Anthropogenic inputs of sulfate can influence microbial community dynamics and disrupt ecosystem functions, particularly through the proliferation of sulfate-reducing bacteria and the release of hydrogen sulfide. Industries may release sulfate-containing pollutants into marine ecosystems through their processes, such as mining activities, metal processing, and chemical manufacturing. Municipal and industrial wastewater can contain sulfate-rich compounds from various sources, including detergents and industrial chemicals. High sulfate levels can support the growth and activity of sulfate-educing bacteria (SRB), leading to the production of hydrogen sulfide (H2S), which can be toxic to marine organisms.

Phosphate (PO_4^{3-})

Phosphate is a form of phosphorus, an essential nutrient for marine organisms. It exists in various chemical forms, primarily orthophosphate (PO_4^{3-}) which is readily available

for biological uptake. Excessive phosphate can disrupt the balance of marine life, promote harmful algal blooms, and alter microbial community dynamics. Agricultural runoff and sewage discharges can introduce high concentrations of phosphate into marine ecosystems. Fertilizers used in agriculture contain phosphates that can be washed into water bodies during rainfall, leading to nutrient enrichment. Industries may release phosphates into water bodies as a result of their processes, such as inorganic phosphates from detergents or cleaning agents. Runoffs from streets, lawns, and gardens where detergents and other products containing phosphates are used may also contribute to increased levels of phosphate in marine ecosystems. Excess phosphate can contribute to eutrophication, a process in which nutrient enrichment stimulates excessive algal growth. High phosphate levels can also favour certain microbial taxa, leading to shifts in microbial community composition. This can alter ecosystem dynamics and potentially promote the growth of pathogenic microbes (Javed *et al*., 2014; Vincent-Akpu & Yanadi, 2014; Hassard *et al*., 2016; Karbasdehi *et al*., 2017; Roll & Fujioka, 2018; Akita *et al*., 2020; Akita *et al*., 2021; Kambire *et al*., 2022).

Oceanic stretches in general particularly the coastal regions have been affected by ever-increasing pollution (Hussain, 2019). Monitoring these parameters, therefore is crucial for assessing the health of marine ecosystems and identifying pollution-related disturbances like the persistence of diarrhoeagenic bacteria especially where their occurrence is simultaneous and impacts each other.

In a study conducted by Abdelzaher *et al*. (2013), data collected from both the microbial and physicochemical analyses of water samples from a Florida marine recreational beach showed a good level of correlation between both parameter categories. The

isolation of faecal coliforms and specific enteropathogens such as *Vibrio vulnificus*, *Staphylococcus aureus*, enterovirus, norovirus, hepatitis A virus, Cryptosporidium species and Giardia species correlated with the levels of pollution that were otherwise determined. Akita *et al.*, (2021) in their research conducted on the Physicochemical interaction with faecal bacteria in the characterization of beach water quality sampled 10 beaches that bordered the three coastal regions in Ghana. Physicochemical parameters such as surface temperature, salinity, specific electrical conductivity, total dissolved solids, pH, redox potential, dissolved oxygen concentration, and saturation in near-shore beach waters were measured. The presence of microbial contaminants specifically faecal indicators such as *Escherichia coli*, *Enterococcus faecalis* and total coliforms were measured as well. The results obtained revealed a positive correlation was established between high counts of the faecal bacterial indicators and physicochemical parameters such as nitrate, conductivity, total dissolved solids, and dissolved oxygen concentrations. The high counts of faecal indicators at the coastal beaches were beyond the USEPA 2006 guidelines. These discoveries were thought to be alarming, of great concern and had health implications for bathers and the marine ecosystem. It was also recommended that the results serve as a baseline study and reference to conduct more research on the quality of beach waters. This is where this study goes further to explore this gap taking into consideration assessment for other diarrhoeagenic bacteria and the impact of seasonal variations on their occurrence.

2.11 Sustainability and human well-being as a function of the health of coastal aquatic ecosystems

An emerging field that is becoming more significant on a worldwide scale is the integrated study of human and ocean health. The relationship between human health

and ocean health is continually being strengthened evidenced by a growing body of research. It is believed that the future of the entire world and, consequently, our health will be substantially impacted by how we treat the oceans now (Borja *et al*., 2020) because environmental health intrinsically plays a vital role in sustaining human health (Whitmee *et al*., 2015). The seas and oceans globally are not exempted from this role (Inniss *et al*., 2016; Gascón *et al*., 2017; Elliott *et al*., 2018; Gollan *et al*., 2019). This significant relationship which has an impact on the global population remains one that has received little attention in terms of study (Depledge *et al*., 2017; Fleming *et al*., 2019; WHO, 2017). When the health statuses of ecosystems like aquatic ecosystems are impaired by the pollutants, the services they render to man are equally impaired (De Groot *et al*., 2013; Pueyo-Ros *et al*., 2018). Pollutants like microbial pathogens in coastal waterways contribute significantly to the burden of disease. Few estimates place the number of individuals afflicted by respiratory diseases at more than 50 million, and gastrointestinal diseases at more than 120 million due to swimming and bathing in wastewater-polluted coastal waterways (Shuval, 2003; Abdelzaher *et al*., 2010). The food chain can also be contaminated by sewage that enters marine waters. Seafood, especially fish and molluscs tend to harbour microbial pathogens (Iwamoto *et al*., 2010).

The desire for excellent physical health is related to the desire for people and society to reduce exposure to harmful pollutants. Many different ways that toxicants might impact ecosystem services ultimately have impacts on human health (Soares & de Souza Porto 2009; Summers *et al*., 2012). Research with systematic approaches to the implications of aquatic ecosystems for human well-being is now beginning to emerge with

significant gaps in knowledge now being acknowledged (Grellier *et al*., 2017; Fleming *et al*., 2019). Some of these gaps include feeble comprehension of the judicious use of ecosystem provisioning services and consequences on the health of humans (Borja *et al*., 2020). These gaps are likely a result of the necessity for interdisciplinary and cross-sectoral research on the relationship between human and ocean health. In other words, there is a need for cooperation between the domains of medicine and public health and the economic, environmental, oceanic, social, and behavioural sciences, as well as many stakeholder groups. (Barragán & de Andrés, 2015). This ensures that there are concerted, holistic and transdisciplinary approaches towards ensuring the availability and sustainable management of water and sanitation for all (SDG 6), reducing marine pollution (SDG 14-14.1) and ultimately ensuring healthy lives and promoting well-being for all at all ages (SDG 3).

2.12 Perceptions of polluted marine ecosystems and implications for human health

Health-related risk perceptions have a key role in influencing behaviours that promote good health and are essential elements of behaviour modification theories. Someone's goal or reluctance to adopt a particular behaviour will be motivated or hampered by their thoughts and feelings. Therefore, behaviours that promote or seek out health (vaccinations, seeking appropriate health care, adopting healthy lifestyles etc.) might be influenced by how we perceive a possible risk to our health and well-being (Anthonj *et al.*, 2022).

Water serves as the vital link between society and the environment, being at the heart of sustainable development, energy and food production, healthy ecosystems, and human health and well-being (UN-Water, 2018). Water security and human health

interactions are influenced by spatiotemporal dynamics and vary by location, including urban, peri-urban, rural, and informal settlements, as well as socioeconomic differences (Anthonj, 2021). According to the Science Advice for Policy by European Academies (SAPEA), the continuous occurrence of anthropogenic-induced pollution in marine ecosystems is partly because of the false notion that the seas and the global ocean could absorb and recycle all forms of toxins. This has consequently resulted in increased dangers to the environment and human health (SAPEA, 2019). Over time, perception-built behaviours shape the culture and outlooks an individual has within a community. In this instance, reformation can only have an impact if it starts from within that community and with a trusted ally. This can be local religious, traditional, or even council leaders or members (Akpabio, 2012). Lack of innate ability to see and comprehend the reasoning behind the issue and resource constraints make it difficult to modify behaviour. The most prevalent resource constraints are those related to formal education, information access, and poverty (Gupta *et al.*, 2012). The selected communities for this study identify with these constraints. Their frequent interactions and dependence on the coastal aquatic ecosystems despite the poor aesthetic outlooks observed at various points are not at all hindered. These low-lying, climate change-impacted coastal communities have visible evidence of aquatic ecosystem pollution from municipal waste and poor sanitary practices like open defecation and indiscriminate household waste disposal. It goes to show how they perceive their actions and the state of the environment and its impact on their health. With these in view, behaviour modification interventions that are adapted to the target population's present behaviours, knowledge, and views will be most effective (Watson *et al.*, 2015).

Their cultural systems and norms must also be considered to develop and complement effective interventions (Sundaram *et al.*, 2014).

It is essential to identify current views about the connection between disease and the environment and how these beliefs relate to practises since community-level environmental management is becoming increasingly important as a part of disease control (Randell *et al.*, 2010). Herbst *et al.* (2009) also recommended that for the development of behaviour modification interventions that are adapted to regional demands, a multi-stakeholder participatory approach was highly recommended. Here interventions are easily comprehended, adopted and adapted.

2.13 Conceptual framework

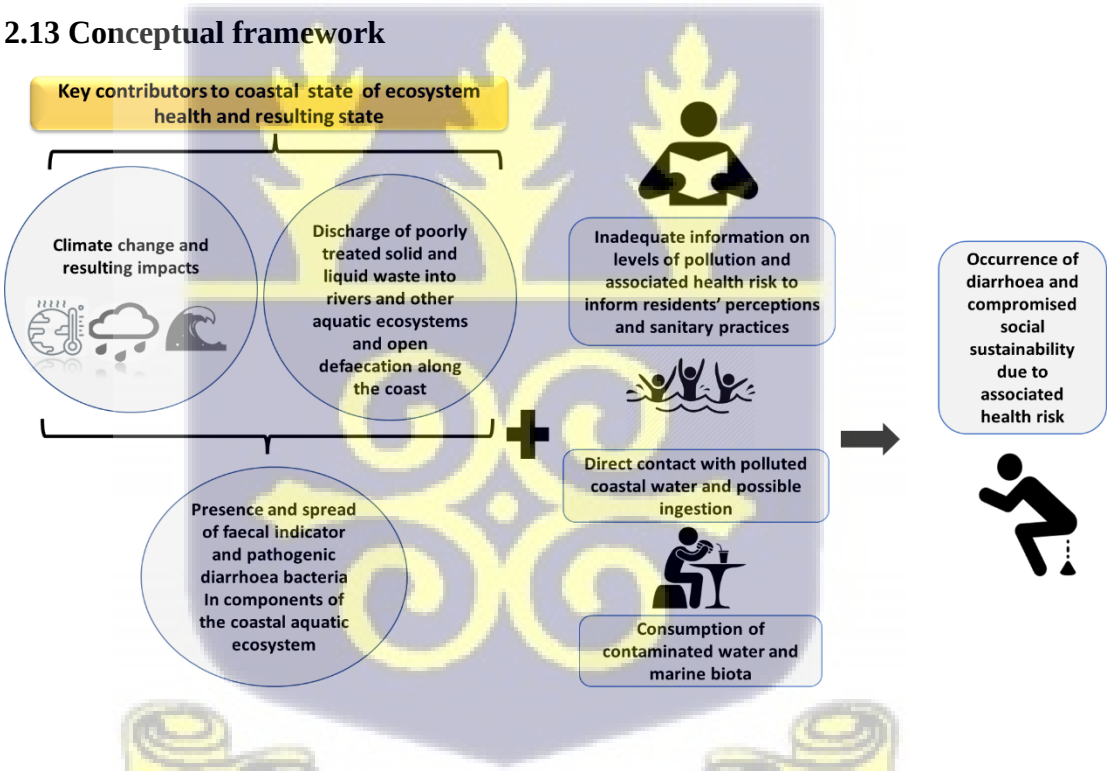

Figure 2.1 Adapted conceptual framework of the relationship between coastal aquatic ecosystems' health and diarrhoea transmission pathways

(Shuval, 2003; WHO, 2003; Vidon *et al.*, 2008; WHO 2009; Abdelzaher *et al.*, 2010; Cho *et al.*, 2010; Fernández-Delgado & Suarez, 2009; Ratajczak *et al.*, 2010; Chu *et al.*, 2011; Korajkic *et al.*, 2011; Liang *et al.*, 2013; McLellan & Eren 2014; Mulamattathil *et al.*, 2014; Hassard *et al.*, 2016; Sedlacek *et al.*, 2016; SAPEA, 2019, Borja *et al.*, 2020; Kemajou, 2022).

Legend

Discharge of poorly treated municipal solid and liquid waste into aquatic ecosystems and open defecation along the coast contributes to the presence of diarrhoea-causing pathogenic bacteria. This can also contribute to their presence in aquatic biota, and sediments. Climate change and its effects like sea-level rise, tidal flooding, and storm surges, facilitate the spread of these bacterial pathogens to and from the coast. Direct contact and consumption of contaminated water and aquatic fauna make them vectors for the diarrhoeal-causing bacteria. These make the coastal aquatic ecosystems transmission pathways for diarrhoea. Ill-informed perceptions about these pathways increase the risk of diarrhoea contraction and hamper social sustainability and well-being (Figure 2.1).

CHAPTER THREE

3.0 MATERIALS AND METHODS

This chapter focuses on a detailed study of coastal communities along the Central and Eastern Coasts of Ghana. It describes the geographical and geomorphological characteristics of the study areas, emphasizing their susceptibility to climate change effects and poor sanitation practices. The selected communities are introduced, along with their vulnerabilities to rising sea levels, flooding, and storm surges. This study was conducted under the auspices of the Umbrella project, Coastal Community Resilience to Climate Change and Diarrhoea (C2RCD) project under the sponsorship of the Danish International Development Agency (DANIDA). The project, overall, is aimed at generating long-term data to understand the dynamics of biophysical and climatic factors on coastal ecosystems to inform diarrhoeal management in coastal communities (C2R-CD, 2022).

The chapter outlines the research methodology, which employs a mixed-method approach involving both quantitative and qualitative analyses. It explains the collection of various samples, including water, sediment, and biota, from the study areas. The laboratory analyses cover a range of parameters, such as water quality indicators, nutrient concentrations (nitrate, phosphate, sulfate), and the presence of microbial indicators and selected pathogenic bacteria. Quality control measures and standard methods are described to ensure the accuracy and reliability of the analyses. The chapter concludes by highlighting the importance of assessing coastal aquatic health status and applying established guidelines for evaluation.

3.1 Study area

This study was focused on coastal communities along the Central and Eastern Coasts of Ghana. Ghana is a low-lying West African country (30m above sea level), located at 7.9465°N, 1.0232°W on the coast and bounded by the Gulf of Guinea. It has four administrative coastal regions, Volta, Greater Accra, Central, and Western Regions (Jonah *et al*., 2017). Three geomorphologic zones (Central, East and West) can be identified as the major coastal zones in Ghana spanning approximately 551km out of its total span of 238,533 km^2. The West Coast covers 95 km including soft, fine-sand beaches and coastal lagoons. A 321km long coast with rocky headlands, rocky shorelines, littoral sand barriers, and coastal lagoons makes up the Central Coast. The Central Coast extends from the estuary of River Ankobrah close to Axim and to Prampram on the East coast. A Sand beach line of 139 km covers the Eastern Coast, with coastal lagoons such as Keta Lagoon, Volta Estuary, and Songor Lagoon. It has the deltaic estuary of the Volta River located halfway along. Its extension proceeds from Prampram to Aflao along Togo's border (Armah, 2005; Lamptey *et al*. 2010).

The selected coastal communities after several surveys under the auspices of the Coastal Community Resilience to Climate and Diarrhoea (C2R-CD) project, were identified as those that were low-lying and prone to climate change effects like rising sea levels, flooding events and storm surges. The communities also presented poor sanitation habits which increased their vulnerability to contracting diarrhoeal diseases as a result of primary or secondary impacts. These communities are but a few faced with the aforementioned challenges. However, these communities were selected due to high incidences of diarrhoea, and resource and time limitations.

The study areas as represented in Fig 3.1 were Anyako, Anyanui, and Atiteti in the Volta Region, Mumford in the Central Region and Gbegbeyise in the Greater Accra Region.

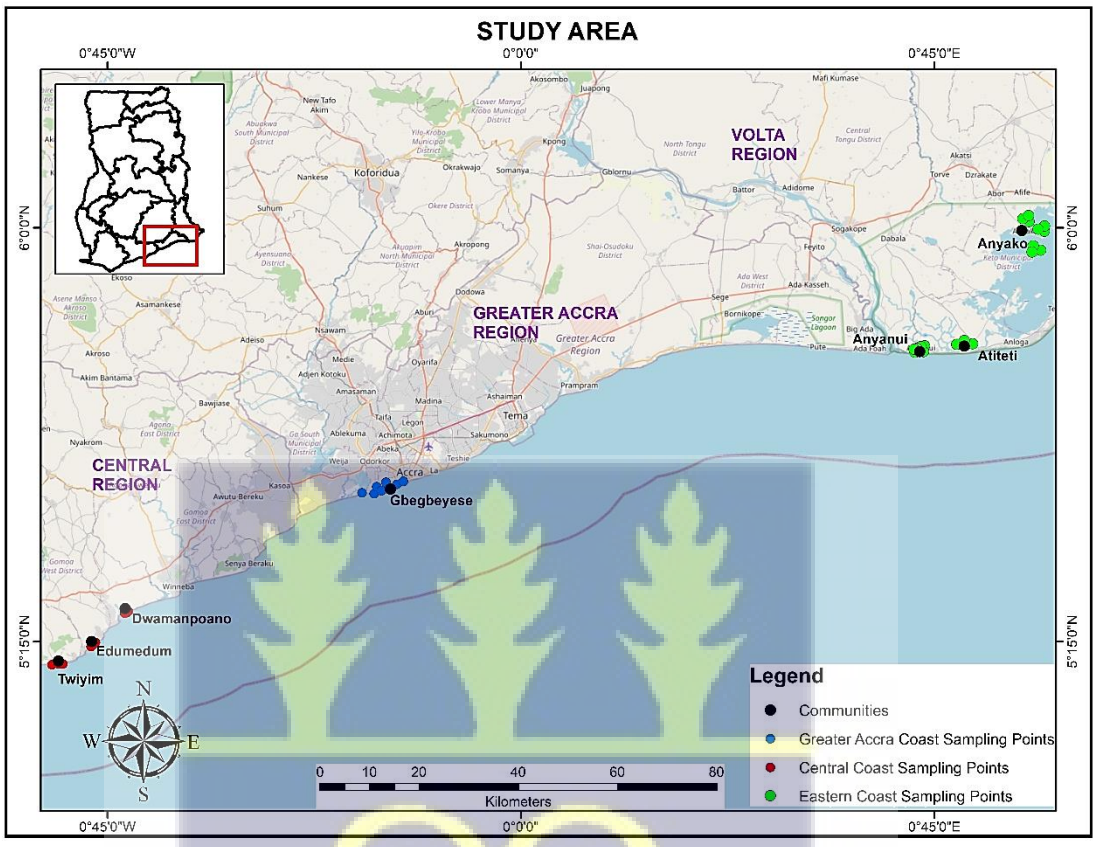

Figure 3.1 Map of Study Areas

3.1.1 Study Area 1 - Selected coastal communities on the Eastern Coast of Ghana

Anyako is situated in the Volta Region under the sub-administrative authority of the Keta Municipal a low-lying coastal plain on the Eastern Coast of Ghana. Bordered by the Keta Lagoon, it lies between Longitudes 0.30E and 1.05W and Latitudes 5.45N and 6.005S (Fig 3.1). Anyako is a fishing community that is prone to flooding events with increased rainfall occurrence. Atiteti and Anyanui are also located on the Eastern coast and are coastal communities in the Volta Region under the sub-administrative authority

of the Anloga West District Assembly. Atiteti at latitude 6.13406°N and longitude 0.45887°E (Figure 3.1) has an elevation of about 15m (49) feet above sea level. It is a fishing community characterised by sandy beaches, a dry climate, relatively low rainfall, and progressive coastal erosion due to climate change effects. Anyanui at Longitude 5° 47' 0" North and 0° 44' 0" East (Figure 3.1) is also a low-lying community in one of Ghana's prominent coastal wetlands with a vast expanse of mangrove plantations. Anyanui's residents in this location are engaged in livestock, fish, oyster, and mangrove firewood farming.

3.1.2 Study Area 2 - Selected coastal communities on the Central Coast of Ghana

This study area includes four locations. Edumedum, Dwampoano, and Twiyim coastal communities all situated in the township of Mumford are under the Gomoa West district assembly (GoWDA), in Central Region, Central Coast – Ghana. The coastal township of Mumford is in the Gomoa West District, Central Region, with geographical coordinates Longitude 05°.15.653' North and Lattitude 000°45.373' West (Fig 3.1). As of 2018, Mumford had a settlement population of 25,876 people. It is typically a fishing community with a few other professionals and white-collar engagements alongside.

Gbegbeyise under the Ablekuma West district assembly (AbWDA), Greater Accra Region, Central Coast Ghana, is geographically located at Latitude 5°31'12.8"N, longitude 0°16'15.7" W (Fig 3.1). This community is frequently inundated as a result of sporadic spring tides. The estimated elevation of this terrain is about 114m above sea level. At one end of the Gbegeyise beach is an estuary known for being visibly polluted with household waste and a pungent odour that stems from the peri-urban town of Ablekuma in the Greater Accra Region.

3.2 Research Philosophy

The research philosophy underlying this study is rooted in a combination of positivism and interpretivism, with an overarching goal of generating a holistic understanding of the complex interactions between climate, anthropogenic activities, and ecosystems' health within coastal communities along the Central and Eastern Coasts of Ghana.

Positivist elements are evident in the quantitative aspects of the research, particularly in the collection and analysis of physicochemical data and microbial indicators. The adherence to standardized sampling procedures and established laboratory methods to objectively measure water quality parameters. The focus on numerical data enables the identification of trends, correlations, and potential causal relationships, contributing to a scientific understanding of the observed phenomena.

Conversely, interpretivist elements emerge through the qualitative aspects of the study, such as engaging in focus group discussions with community residents. By incorporating local perspectives, attitudes, and behaviours regarding sanitation practices and climate change impacts, the research seeks to grasp the subjective experiences and socio-cultural factors influencing human-environment interactions. This interpretivist stance recognizes the importance of context and the need to uncover deeper meanings and narratives that quantitative data alone might not capture.

The research philosophy demonstrates a pragmatist orientation, as it integrates both positivist and interpretivist approach to address the multi-faceted nature of the research question. By combining quantitative measurements with qualitative insights, the study aims to provide a comprehensive and nuanced understanding of the potential implications for both environmental and public health.

3.3 Study Design

The study design for this research was correlational in nature due to its focus on examining relationships and associations between different variables such as environmental factors (e.g., water quality parameters, microbial indicators), and human behaviours (e.g., sanitation practices) without manipulating or controlling them. Patterns, trends, and potential links between variables to understand how changes in one variable might be related to changes in another were explored. The study quantitatively analyzed the collected data using statistical methods to identify potential correlations. Statistical analyses, such as calculating correlation coefficients, reveal whether certain water quality parameters (e.g., coliform count) are associated with the prevalence of diarrhoea-causing bacteria.

Mixed-methods approach that combined quantitative data on water quality with qualitative insights from focus group discussions, was utilized. This provided a comprehensive understanding of the complex interactions between environmental factors, human behaviours, and health. This approach can reveal nuanced correlations that may not be apparent through quantitative analysis alone.

3.4 Collection of samples

Reconnaissance visits were conducted at the onset of the study. This was done to augment first-hand appreciation of the nature and subtleties of the sanitary practices in the study areas which affect the coastal aquatic ecosystems and expose residents to diarrhoeal pathogens in the face of climate change.

Coastal seawater (Beach water), coastal lagoon water, coastal mangrove waters, and their biota (fish, bivalves, crabs) and sediments were sampled from around the

coastlines of the study areas. A total of four (5) sampling areas were selected based on their geographical locations, low reliefs, and the presence of especially visible evidence of pollution by municipal waste and open defecation. Within the 5 areas, (13) sampling sites were sampled. All samples were taken in triplicates and were taken for six (6) months. Three (3) months each were designated for sampling in seasons of no rainfall and seasons of rainfall. Samples collected were subjected to physicochemical and microbiological analyses.

3.4.1 Water sampling

Water sampling for nutrients and physicochemical properties of the water

Waters closer to the coastline in all study areas (beaches, inland lake waters/waterbody surrounding mangrove areas where present) were sampled. Samples were taken randomly from three (3) sampling points at all the study sites (i.e., water samples were taken in triplicates from the waterbody being sampled). The samples were collected in new sterile bottles which were dated and labelled according to the codes assigned to each sampling site for proper identification. Sampling bottles were rinsed with the water from the sampling sites to ensure uniformity of content and lowered back into the water to obtain the sample. Samples were then placed in a cooler containing ice and transported to the laboratory for ex-situ (off-site) analysis within twenty-four (24) hours of collection. These steps were taken to ensure samples' conditions were maintained to serve as good representatives of the water bodies which they were sampled from.

Water sampling for biochemical oxygen demand (BOD) determination

Well-labelled sterile BOD bottles were used to carefully sample water at three (3) points at all study sites. The Bottles were rinsed with water from the sampling points and

lowered back into the water to obtain the sample. Air-tight amber BOD bottles were carefully filled to the brim avoiding any bubbles or air spaces within the water samples and then capped tightly. These precautions were taken to avoid the occurrence of contamination and false positive results. Samples were placed in a cooler containing ice and transported to the laboratory for BOD analysis within twenty-four (24) hours of collection.

Water sampling for Microbial analysis

Water sampling for microbial analysis followed the same protocol as described for water sampling for nutrients and physicochemical analysis. Water samples were collected in 500 mL sterile bottles. All samples were taken aseptically by ensuring the right personal protective equipment (PPE) were worn to avoid the introduction of self-microbiota or contaminants into the samples taken. Samples were placed on ice and analysed within 24 hours.

3.4.2 Aquatic fauna (biota) sampling

Commonly exploited aquatic fauna that had been freshly harvested and brought ashore were sampled aseptically on the spot. Biotas sampled in this study were crabs, snails, fish, and bivalves (mangrove mussels).

Fish sampling for microbial analysis: Freshly harvested fish of different species, with red-coloured gills (pink to white-gilled fish are not suitable as discolouration signifies the onset of decay), were aseptically sampled (3 per sampling area if available) into new sterile well-labelled Ziploc bags. Fish samples were placed in a cooler with enough ice because of the rapid rate of decomposition in fish (Kelly & Roy 2020) and then transported to a ready-to-receive laboratory for analysis within 24 hours. In cases where

samples were not processed at the laboratory on arrival, they were stored in the laboratory's cold room at a freezing temperature and processed within 24 hours (Heil, 2004).

The fish species sampled were;

- *Boops boops* Anyako and Atiteti
- *Priacanthus arenatus* and *Chloroscombrus chrysurus* in Mumford
- Atlantic Ghost Crab/*Ocypode quadrata* in Gbegbeyise

Bivalve molluscs sampling for microbial analysis:

Fresh bivalve mollusc samples were aseptically collected from the shoots of mangroves submerged in water, rinsed with sterile distilled water, and carefully placed in well-labelled sterile Ziploc bags. The samples were placed in a cooler with ice and transported to a set-to-receive laboratory for microbiological analysis as soon as possible (Fernández-Delgado & Suarez, 2009). In cases where samples were not processed at the laboratory on arrival, they were stored in the laboratory's cold room at a freezing temperature and processed within 24 hours (Heil, 2004).

Snail sampling for microbial analysis

The same protocol for sampling bivalve molluscs for microbial analysis was applied for the sampling of snails from fishing lagoons at the Anyako fishing community.

3.4.3 Sediment sampling

Random sediment samples from the surface to about 10cm-15cm deep at each sampling site were collected using a suitable sampler (a simple hand spatula or corer for shallow waters and easily accessible waters and an Ekman grab for deeper waters). The samples

were taken in triplicates and placed in well-labelled Ziploc bags. Samplings were done aseptically to avoid external contamination and carefully to avoid disturbing the strata, (HELCOM, 2018). Samples were placed on ice and transported to set-to-receive laboratories for microbial and physicochemical analysis within 24 hours.

Sediment sampling for microbial analysis

Sediment sampling for microbial analysis followed the sediment sampling protocol described above in sediment sampling. All samples were taken aseptically by ensuring the right personal protective equipment (PPE) was worn to avoid the introduction of self-microbiota or contaminants into the samples taken. In cases where samples were not processed at the laboratory on arrival, they were stored in the laboratory's cold room at a freezing temperature and processed within 24 hours (Heil, 2004).

3.5 Laboratory analyses of physicochemical parameters

3.5.1 In-situ determination of temperature, pH, EC, TDS, salinity, and DO of water samples

The temperature, pH, electrical conductivity, total dissolved solids, salinity, and dissolved oxygen of the water samples were measured in situ. The measurements of the parameters were done using the HORIBA U-50 series, a multi-meter water quality checker. The measurements were carried out by fetching water samples from the sampling site with a clean plastic beaker that had been rinsed with the water samples. The probe sensor of the device was first rinsed with the water to be sampled and dipped into the beaker with the sample. The probe was allowed to sit in the sample for a few minutes till the parameter values on the display monitor were stabilized. The readings of the desired parameters were then read and recorded.

3.5.2 Determination of biochemical oxygen demand (BOD) in water

The Biochemical Oxygen Demand (BOD) analysis of the water samples was conducted in a two-phased (in-situ and ex-situ) analysis. The in-situ phase involved recording the initial dissolved oxygen (DO) readings of the sample. The ex-situ or second phase was conducted as soon as samples arrived at the laboratory. This phase involved incubating the water samples at 20^{o}C for five (5) days away from any light source. The DO of the water samples were measured on the fifth day and the BODs of the samples were derived from the difference between the initial and final readings of the DO.

All readings of the DOs at both phases were measured using the HORIBA U-50 series muli-meter water quality checker.

BOD calculation: $BOD_5(mg/l) = D_0 - D_1$.

Where,

D_0= Dissolved Oxygen of the sample measured in-situ (mg/L)

D_1= Dissolved Oxygen of the sample measured after 5 days of incubation at 20°C (mg/l) (APHA, 1999).

3.5.3 Determination of nitrate-nitrogen (NO_3^--N) in water

The concentration of nitrate in the water samples was determined ex-situ shortly after field sampling. The determination was done by first cleaning the spectrophotometer's sample cell with a clean tissue to rid the cell of any matter (eg. Water droplets, fingerprints, dust, etc.). Ten millilitres (10ml) of distilled water was then measured and introduced into the sample cell column of the Spectrophotometer (The HACH Spectrophotometer, Model DR 2010) and placed into the cell holder of the spectrophotometer and the wavelength of the device was set to 500mm. The

spectrophotometer was then turned on and calibrated by measuring the nitrate concentration of the distilled water thereby zeroing the device and making available a reference value. Following the device's calibration, ten millilitres (10ml) of the water sample was measured and introduced into the sample cell and a single nitrate powder pillow reagent was added to the water sample in the cell. The water sample and nitrate powder pillow were evenly mixed by agitating vigorously for one (1) minute and then allowed to remain still for about three (3) minutes. The sample cell with the solution was then placed back into the cell holder. Finally, the spectrophotometry device was turned on and the nitrate concentration of the sample was measured in mg/L NO_3^-N.

3.5.4 Determination of phosphate (PO_4^{3-}) in water

The concentrations of phosphate in each of the water samples were determined ex-situ. The HACH Spectrophotometer, Model DR 2010 was employed to obtain a direct reading of the phosphate concentration. PhosVer 3 phosphate powder pillow reagent was first added to 10ml of distilled water and swirled gently till the powder had completely dissolved. The solution was introduced into the cell tube and the tube was cleaned with a lint-free cloth to get rid of any matter that would interfere with readings and then placed in the spectrophotometer's cell holder. The wavelength of the spectrophotometer was set to 890nm, and the phosphate concentration values of the distilled water were determined to serve as a calibrant. The same procedures were followed to determine the phosphate concentration in the water samples and the values recorded in mg/L PO_4^{3-} (APHA, 1999).

3.5.5 Determination of sulphate (SO_4^{2-}) in water

The HACH Spectrophotometer, Model DR 2010 was also employed in the determination of the sulphate concentration in the water samples. A SulphaVer 4

powder pillow was added to 10ml of distilled water, the mixture was swirled until complete dissolution and formation of a solution. The solution was introduced into a clean sample cell tube of the spectrophotometer. The cell tube was wiped to get rid of any matter that would interfere with readings, placed in the sample cell holder of the spectrophotometry device and the sulphate concentration was recorded with the device set to a wavelength of 450nm. The concentration determined served as a standard to calibrate the device. The concentration of sulphate in samples was subsequently determined following the same procedures. The values were recorded as mg/L SO_4^{2-}.

3.6 Laboratory Analyses of Microbiological Parameters

3.6.1 Total coliform and *Escherichia coli* count determination in water samples using membrane filtration (MF) method

The enumeration of the total coliforms and *Escherichia coli* count was done using the Membrane Filtration (MF) method. Smaller Ten-fold serial dilutions of the water samples were first made due to perceived interference from the turbidity of water and high bacterial count (US EPA, 2014). The dilution was done by mixing 10mL of the water sample with 90mL of sterile phosphate-buffered saline solution to make a 1 to 10 dilution (10mL sample volume). The next series was made by pipetting 10ml of the 1 to 10 dilution and adding it to a fresh 90mL of sterile Phosphate buffered solution to make a 1 to 100 dilution (1mL sample volume) the last dilution was done to give a 0.1mL sample volume (Hach Company, 2012; Schlosser, 2013; US EPA, 2014). The process for each was repeated three times (3 separate Petri dishes were used for each pipetted sample's dilution for the 3 different media required for the three respective types of counts to be done).

Membrane filtration was then conducted by passing 100mL of the 1 to 100 diluted water sample through a sterile filter paper with a 0.45µm pore diameter suitable for recovering the target organisms. The filter paper was placed aseptically using sterile forceps in a filtration flask set up with its cross-marked side facing upwards. The water was filtered through with the aid of an electric vacuum pump. After the water was completely filtered out, the filter paper was taken out, placed on a solid growth media with the cross-marked side facing upwards and incubated for 24 hours at 37°C. The media used for the total coliform count was CM1046 Brilliance *E. coli* (Coliform Selective) Agar. The growth media was prepared by heating (according to the manufacturer's standard that indicated no autoclaving sterilization), allowed to cool to between 40-45°C, poured aseptically into Petri dishes and tested for sterility before use.

Following incubation, the colonies that grew on the growth media for each petri dish were counted and recorded. Colonies counted were identified according to the manufacturer's standards and generally accepted colony morphology. Purple colonies represented *Escherichia coli* whereas pink colonies were representative of other coliforms. The counts were recorded and the HACH limits of 20-80 colonies for significant counts were applied (Hach Company, 2012).

The bacterial count per millilitre of the samples was computed using the equation:

$$\text{CFU/100ml} = \frac{\text{Bacterial colonies counted} * \text{Dilution factor}}{\text{Volume of sample filtered (mL)}} * 100$$

3.6.2 Total coliform and *Escherichia coli* count determination in sediment using the pour plate method

1g of the sediment sample was weighed and introduced into 9mLs of phosphate-buffered saline solution (the diluent) in a sterile Pyrex test tube to make a first ten-fold

serial dilution of the sediment. The dilutions were then mixed properly with a vortex mixer and the dilutions progressed till a fifth ten-fold dilution was achieved. The dilutions were plated, and the colonies were enumerated and computed in CFU/g as conducted for the total coliform *Escherichia coli* count for water samples. CM1046 Brilliance *E. coli* (Coliform Selective) Agar was used to grow bacteria. The growth media was prepared by heating (according to the manufacturer's standard that indicated no autoclaving sterilization), allowed to cool to between 40-45°C, poured aseptically into Petri dishes and tested for sterility before use.

Following incubation, the colonies that grew on the growth media for each petri dish were counted and recorded. Colonies counted were identified according to the manufacturer's standards and generally accepted colony morphology. Purple colonies represented *Escherichia coli* whereas pink colonies were representative of other coliforms. The counts were recorded and the HACH limits of 20-80 colonies for significant counts were applied (Hach Company, 2012).

$$\text{CFU/g} = \frac{\text{Colonies counted} * \text{Dilution factor}}{\text{The actual weight of the sample in a dish (mL)}}$$

3.6.3 Total coliform and *Escherichia coli* count determination in biota

The biota samples were aseptically and individually processed based on the type and part required for analyses. The fish samples were dissected to obtain the gills and gut, the crab samples were dissected to obtain the entire edible internal parts, the snails were dissected to obtain their muscular foot, and the oysters, their gills and internal organs.

1g of the desired parts for the biota samples were placed in a low-density polyethene (LDPE) stomacher bag with 9mLs of phosphate-buffered saline solution and

homogenized for 2 minutes using the EXNIZER 400 homogenizer for food examination.

The homogenate mixture was poured into a tube to serve as the first ten-fold dilution (10^{-1}) and from this, subsequent dilutions were carried out till the fifth ten-fold (10^{-5}) dilution was obtained. 1ml of each dilution was plated and the colonies were enumerated and computed in CFU/g as in the total coliform *Escherichia coli* count for water samples. CM1046 Brilliance *E. coli* (Coliform Selective) Agar was used to grow bacteria. The growth media was prepared by heating (according to the manufacturer's standard that indicated no autoclaving sterilization), allowed to cool to between 40-45°C, poured aseptically into Petri dishes and tested for sterility before use.

Following incubation, the colonies that grew on the growth media for each petri dish were counted and recorded. Colonies counted were identified according to the manufacturer's standards and generally accepted colony morphology. Purple colonies represented *Escherichia coli* whereas pink colonies were representative of other coliforms. The counts were recorded and the HACH limits of 20-80 colonies for significant counts were applied (Hach Company, 2012).

$$\text{CFU/g} = \frac{\text{Colonies counted} * \text{Dilution factor}}{\text{The actual weight of the sample in a dish (mL)}}$$

3.6.4 Isolation and identification of indicator and selected diarrhoea pathogenic bacteria in water, fish, and sediment samples

Isolation of *Escherichia coli* in water, fish, and sediment

The samples were streaked directly (in the case of water) or from first dilutions (Sediment, and Biota) onto MacConkey Agar (OXOID) and Uri-Select 4 Agar (BIO RAD) with a 10µL inoculating loop. The streaked plates were incubated at 37°C for 24 hours and observed after for presumptive colonies characteristic of *E. coli.* On MacConkey agar presumptive colonies considered were lactose-fermenting pink and dark pink colonies with slightly dull and ring-shaped. On Uri-Select 4 agar, pink, raised, smooth-surfaced 1mm to 2mm sized colonies were considered as presumptive colonies. All presumptive colonies of *Escherichia coli* and other microorganisms that grew were sub-cultured onto fresh Uri-Select culture media to obtain pure isolates of the presumptive colonies.

Isolation of Salmonella and Shigella in Water, Fish, and Sediment

The samples were enriched in Selenite Cystine Broth as their presence in certain environments or samples may differ and may present complex growth requirements (fastidious microorganisms). The enrichment overall helped in the recovery of Salmonella species and also inhibited the growth of gram-positive and other non-pathogenic enteric bacteria.

The enrichment was done by introducing 1mL of the sample (the original sample for water and the 10^{-1} dilutions for the biota and sediment samples) into sterile tubes containing 10mls of Selenite Cystine Broth spiked with sodium biselenite. The tubes were then incubated at 37°C for 24 hours. Following incubation, tubes that showed

turbidity or slight changes were streaked on Salmonella Shigella Agar (OXOID) selective growth media and incubated at 37°C for 24 hours. After the incubation, the culture plates were observed phenotypically for the growth of colonies characteristic of Salmonella and shigella. Non-lactose fermenting hydrogen sulphide-producing transparent colonies with black centres and non-lactose non-hydrogen sulphide-producing colourless colonies for Salmonella species and Shigella species respectively. Presumptive colonies were sub-cultured onto fresh Salmonella Shigella Agar plates to obtain pure cultures.

Isolation of Vibrio species in Water, Fish, and Sediment

Due to the difficulty in recovering *Vibrio species* from natural water samples, the samples were enriched in Alkaline Peptone Broth. The enrichment was done by introducing 1m of the sample (the original sample for water and the 10^{-1} dilutions for the biota and sediment samples) into sterile tubes containing 9mLs of Alkaline Peptone Broth and incubating it for 6 to 8 hours. A loopful of the incubated sample in the broth was then sub-cultured onto thiosulfate-citrate-bile salts-sucrose (TCBS) agar (PARK Sci. Ltd) and then incubated at 37°C for 24 hours. After 24 hours, the growth of colonies characteristic of Vibrio species, flat dull yellow colonies of 2-3mm in size, were considered presumptive. Presumptive colonies and other microorganisms that grew were sub-cultured onto fresh TCBS Agar plates to obtain pure cultures.

3.6.5 Microscopic identification of presumptive colonies of target bacteria gram staining

A drop of normal saline was placed on a grease-free glass slide and a colony from the agar plate of pure culture was emulsified in the saline by teasing gently in order not to

destroy the cells of the organisms and a smear was made. The smear was heat-fixed and was allowed to air dry thoroughly. The smear was then flooded with crystal violet and allowed to stand for one minute, the excess dye was poured off, rinsed away with water and drained. The next step was the addition of Gram's Iodine used to flood the slide and allowed to stand for one minute; poured off, rinsed away with water and drained. 95% alcohol (acetone) was applied to the slide for a few seconds, washed off with water then Safranin was applied, and the slide was allowed to stand for 60 seconds then rinsed off with water, drained, and allowed to air dry properly. After this, a drop of immersion oil was placed on the stained smear and examined under the oil immersion objective (100x objective). Presumptive colonies of *Escherichia coli* and *Salmonella species* were expected to be gram-negative rods while the *Vibrio species* were expected to be gram-negative curved rods.

3.6.6 Identification of *Escherichia coli*, Salmonella, and Vibrio species (MALDI-TOF)

The Matrix-assisted laser desorption/ionization-time of flight (MALDI-TOF) mass spectrometry (MS) was used in identifying the presumptive colonies of the target organisms.

A 1µL disposable plastic loop was used to pick a single pure colony from a nutrient agar plate that had a subculture of pure colonies from presumptive colony plates. The colony was emulsified on the desired test spot (single colony space) on a MALDI-TOF MS target plate. The emulsified colony was then treated with 1µL of formic acid and then subsequently overlain with 1µL of MALDI-TOF matrix solution. The plate was allowed to air dry in a fume hood and then placed in the ionization chamber of the mass spectrometer device. A mass spectrum for the isolate on the test spot of the plate was

then generated. The generated spectrum was compared against a database of mass spectra by the MALDI-TOF software and the most accurate matching spectrum was detected and the corresponding microorganism and its species identification were generated (Patel, 2015).

3.6.7 Quality control

All microbiological analyses were done aseptically, with strict adherence to biosafety techniques, and under the supervision of well-trained laboratory technicians.

The procedures for the microbial and physicochemical laboratory analyses were all done according to the APHA 20th edition Standard Methods for the Examination of Water and Wastewater (1999) except otherwise referenced.

All growth media to be used were subjected to sterility checks by incubating them at appropriate temperatures to observe for growth of contaminants before being used for samples. All procedures were carried out in a functional fume hood or designated laboratory with all aseptic conditions in place to avoid contamination or generation of false positive results and harm.

3.6.8 Determination of coastal aquatic health status and standards applied

The water quality status of the coastal waters sampled was determined using the upper 95-percentile classifications based on the European Union directives for bathing and recreational waters (Table 3.1) (EU, 2006).

Before the classification was carried out, 95-percentile values for each sampling area were derived using the formula below:

Upper 95-percentile = antilog (μ + 1. 65 σ)

Where;

μ = arithmetic means of the log10 values of all the individual bacterial counts in the microbiological data

σ = standard deviation of the log10 values of all the individual bacterial counts in the microbiological data

Table 3.1 95th percentile evaluation based on the European Union directives for bathing and recreational waters (EU, 2006)

Water Quality Quality				
Parameter name	**Excellent**	**Good**	**Sufficient**	**Poor**
Intestinal Enterococci (CFU/100ml)	100 (95-percentile evaluation)	200 (95-percentile evaluation)	185 (90-percentile evaluation)	The set of bathing water quality data for the last assessment period shows percentile values for microbiological enumerations that are worse than the 'sufficient' values
Escherichia coli (CFU/100ml)	100 (95-percentile evaluation)	200 (95-percentile evaluation)	185 (90-percentile evaluation)	

3.7 social survey

A focus group discussion was carried out to obtain data from stakeholders within the selected coastal communities where the study was conducted. This was done using guided questions to find out their knowledge level on diarrhoea, its transmission pathways within the coastal aquatic ecosystems, exposure to possibly contaminated

biota, sediment, and seawater, and sanitary practices before and after exposure that could either increase their chances of contracting diarrhoea.

The use of a focus group discussion strategy was adopted to gain a deep contextual understanding of the communities' experiences, attitudes, beliefs, and practices related to water quality, sanitation, and health. This understanding is crucial for interpreting quantitative data and generating comprehensive findings. This strategy also helps participants freely express their thoughts and feelings which are not tied to a range of possible answers giving more room for exploration. New complex interactions from these discussions also help in generating new hypotheses that encourage participants and by extension, community ownership should interventions and policies arise from the research. Ethical clearance for the study to be conducted within the communities was sought through the College of Basic and Applied Sciences (University of Ghana) (Plate 12). Community leaders were also informed and given prior notice before every visit to the communities. To ensure the community members and researcher were all at ease, the community leaders provided a reputable community member who assisted with gathering the participants and helping with language translation where needed.

The focus group discussions were conducted with only adult males and females who were 18 years and above. The discussion comprised four (4) groups each for all communities. The participant groups for each community were; adult females (41 years above); adult males (41 years above); young females (18 to 40 years); and young males (18 to 41 years). Each group comprised of eight (8) participants each. The selection of the participants was purposive in terms of their age. However, convenience sampling based on their availability and willingness to take part in the discussion and

communicate their understanding was used to select adult participants who eventually took part. Care was taken in selecting participants to avoid false positive generalisation, for example picking a group of friends of about the same age.

The groups were segregated for the discussions i.e., each focus group (adult male, adult female, young male, and young female) was handled separately. This was done to create a more comfortable and inclusive environment, allowing participants to express themselves freely without the potential influence or judgment of the opposite gender. This led to deeper insights and richer discussions.

The discussions were recorded with a handheld recorder alongside handwritten notes. The recordings were transcribed into notes using the Otter.ai voice note transcriber and by keen listening. The discussions were reported under thematic areas, quoting individual responses where a strong opinion needed to be highlighted.

3.8 statistical analysis

Descriptive analysis such as the percentages, mean, standard deviation, minimum and maximum values of the bacterial count, and the values of the Physico-chemical and microbial parameters measured were carried out using Microsoft Excel and Statistical Package for Social Sciences (SPSS) Version 26.0 (SPSS.Inc.USA). Correlation analysis adopting the correlation coefficients 0.05 and 0.01 was also carried out using SPSS v26.0 to show associations and strengths of associations. Values obtained for Pearson correlation coefficient ® that were closer to 1 were considered to have strong associations. Differences in the abundance of faecal indicator bacteria and pathogens between biota, sediment and seawater of each community were also depicted using Microsoft Excel.

Principal component analysis (PCA) was used to summarize the variables measured, identify the most contributing parameters, and identify trends and patterns between the individual parameters measured. The principal component analysis was carried out using the R Project for Statistical Computing Version 4.0.4 and Statistical Package for Social Sciences (SPSS) Version 26.0 (SPSS.Inc.USA).

CHAPTER FOUR

4.0 RESULTS

Introduction

A comprehensive report on the results obtained from the laboratory analyses of samples collected and their corresponding statistical analyses are presented using figures, tables and descriptive statements in this chapter.

A social survey on the knowledge level and perceptions of diarrhoea, sanitary practices and the possibility of aquatic ecosystems being diarrhoea transmission pathways are documented in this chapter.

A total of three hundred and forty-two (342) water samples, three hundred and forty-two (342) sediment samples and seventy-five (75) commonly exploited biota samples were collected over a period of six (6) months from all the five selected coastal communities for this study. All samplings were done in triplicates.

4.1 Physico-chemical parameters of the water samples

4.1.1 pH

The mean values of the pH concentrations of the water samples are presented below (Figure 4.1).

Gbegbeyesie Estuary was the only community with most of its records falling below the Canadian recreational water guidelines (2012), especially in the dry season. Anyako and Anyani exceeded the lower limit for the Canadian recreational water guidelines (2012) in the dry season. (Figure 4.1).

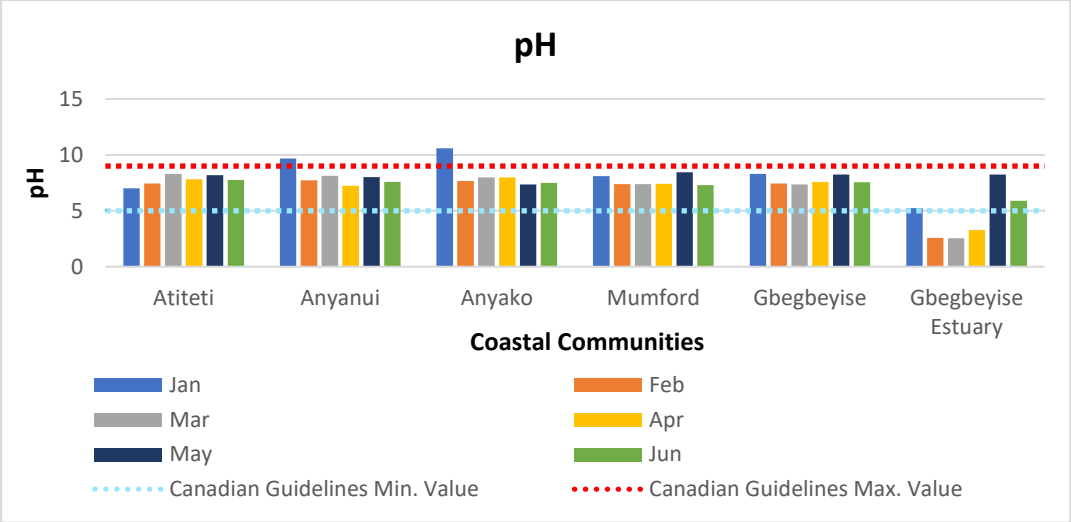

Figure 4.1 Monthly pH Measurements per community

4.1.2 Temperature

The mean values of the observed temperatures of the water samples are presented below (Figure 4.2);

The estuary at Gbegbeyise had the highest temperature record. The records for most communities in both seasons did not exceed the WHO upper and lower limit guidelines comfortable and suitable for swimmers being 20 to 30°C. This occurred both in dry and wet seasons (Figure 4.2).

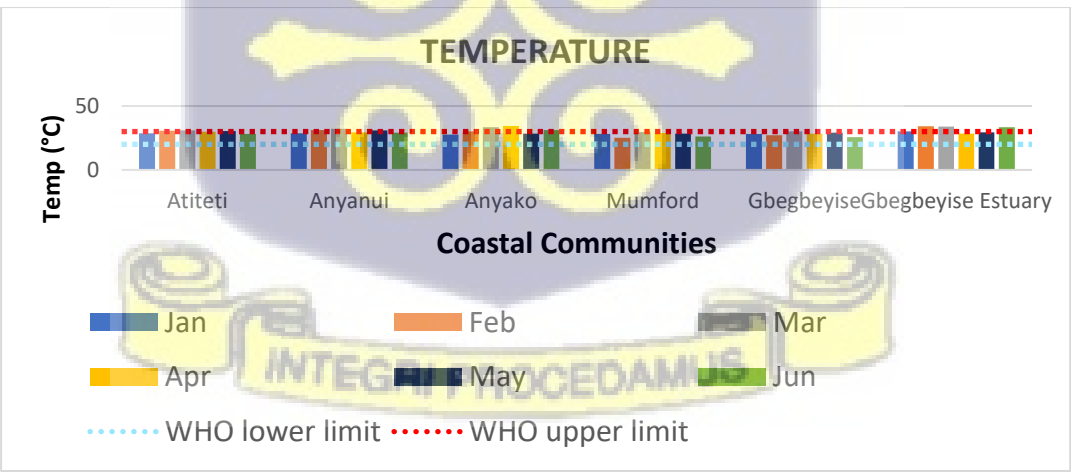

Figure 4.2 Monthly temperature measurements per community

4.1.3 Electrical conductivity (EC)

The mean values for the observed electrical conductivity values of the water samples collected are presented in Figure 4.3).

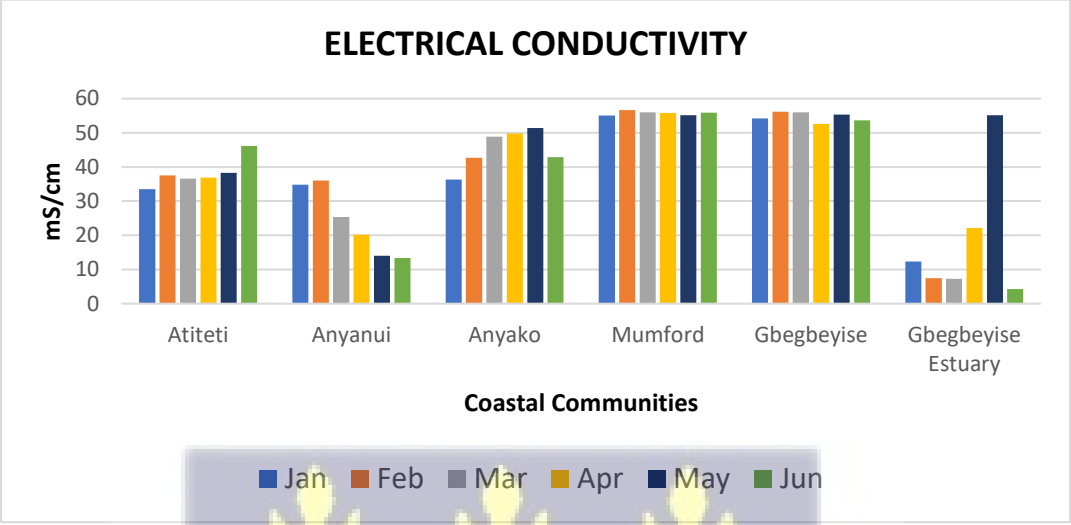

Figure 4.3 Monthly electrical conductivity measurements per community

The electrical conductivity for the communities from the highest to the least records in descending order were Mumford Beach, Gbegbeyise Beach, Anyako fishing lagoons, Atiteti Beach, Anyanui Mangrove Swamp and the last Gbegbeyise Estuary (Figure 4.3).

4.1.4 Total dissolved solids (TDS)

The mean values of the total dissolved solids present in the water samples in grams per litre (g/L) are presented below (Figure 4.40).

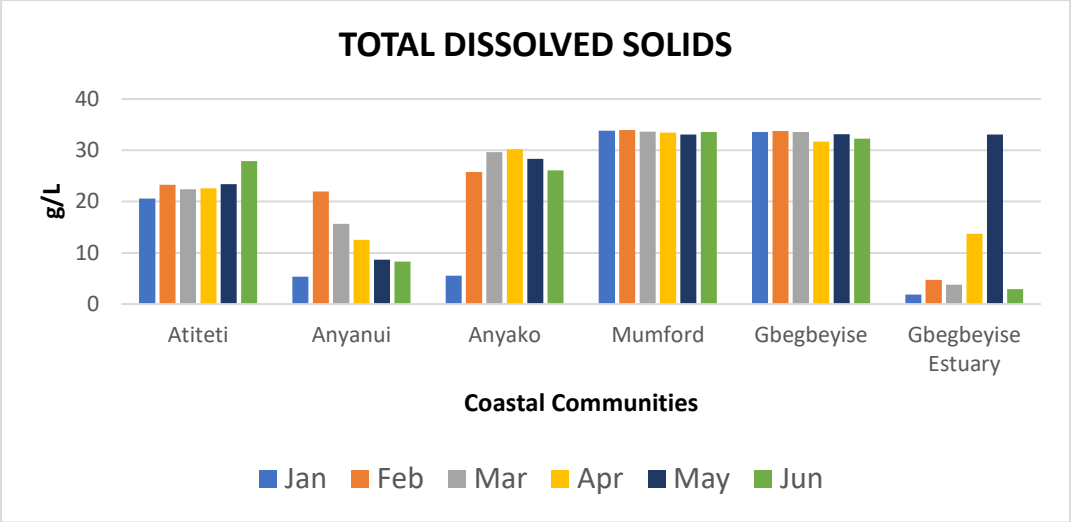

Figure 4.4 Monthly TDS measurements per community

The records for total dissolved solids for the communities from the highest to the least records in descending order were Mumford Beach, Gbegbeyise Beach, Anyako fishing lagoons, Atiteti Beach, Anyanui Mangrove Swamp and the last Gbegbeyise Estuary. Atiteti, Anyako, and Gbegbeyise's Estuary had their highest records in the rainy season while Anyanui, Mumford, and Gbegbeyise's Beach had their highest records in the dry season (Figure 4.4).

4.1.5 Salinity

The mean values of the salinity levels of the water samples per community are presented below (Figure 4.5):

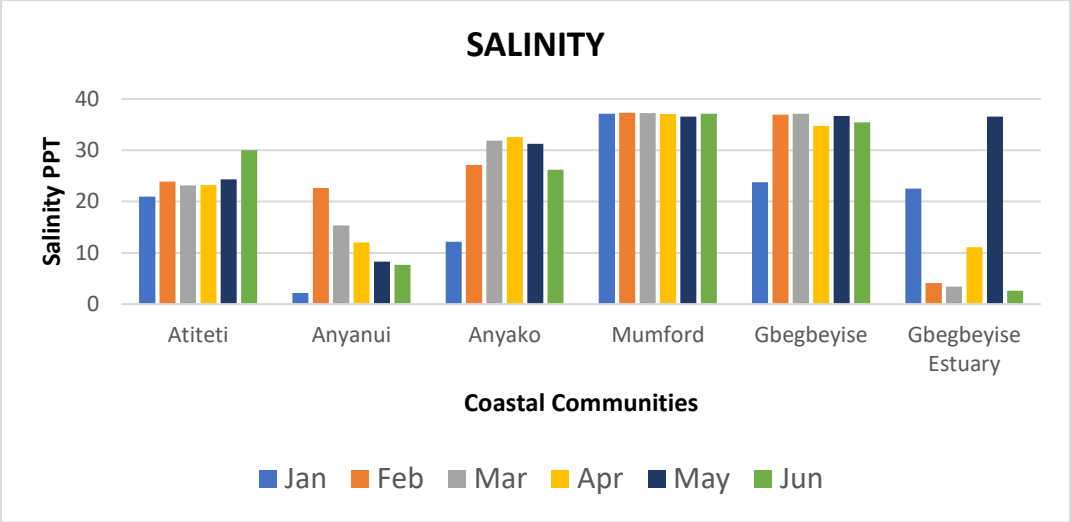

Figure 4.5 Monthly salinity measurements per community

The beach water samples had the highest salinity levels which did not show any significant decrease between the seasons. The estuary had higher salinity levels in the rainy season while the Anyanui Mangrove Swamp had higher salinity levels in the dry season which steadily decreased in the rainy season (Figure 4.5).

4.1.6 Dissolved oxygen (DO)

The mean values of the dissolved oxygen present in water samples have been presented in Figure 4.6 below. The Lowest DO records were observed mostly in the rainy season.

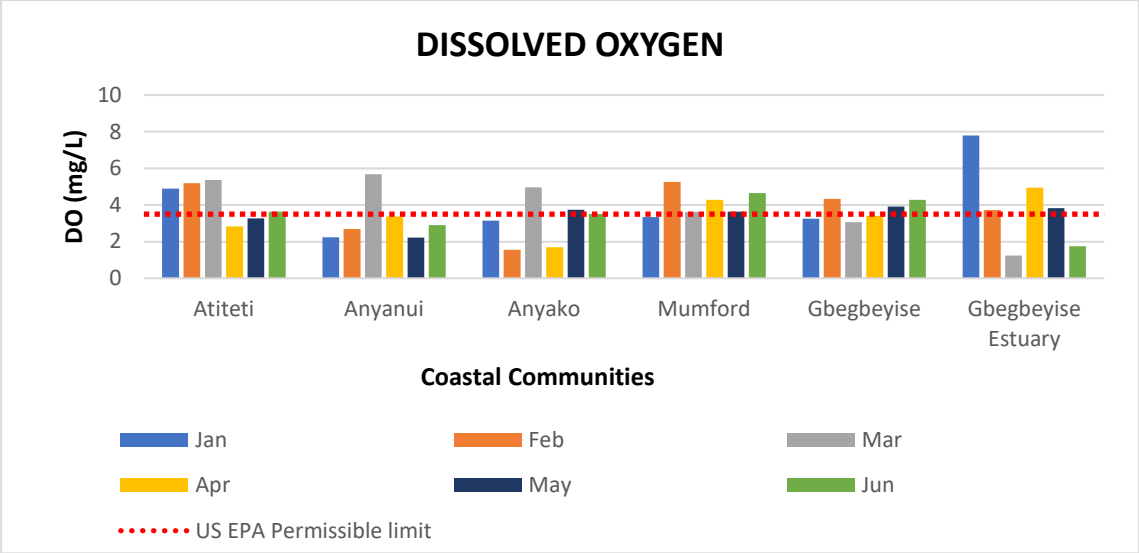

Figure 4.6 Monthly dissolved oxygen measurements per community

4.1.7 Biological oxygen demand (BOD)

The mean values of the BOD concentration present in water samples have been presented in Figure 4.6 below. The biological oxygen demand (BOD) patterns fluctuated between the seasons but still had higher mean values in the wet than in the dry season. Gbegbeyise Estuary and the Anyako Fishing Lagoon had the highest records overall (Figure 4.7).

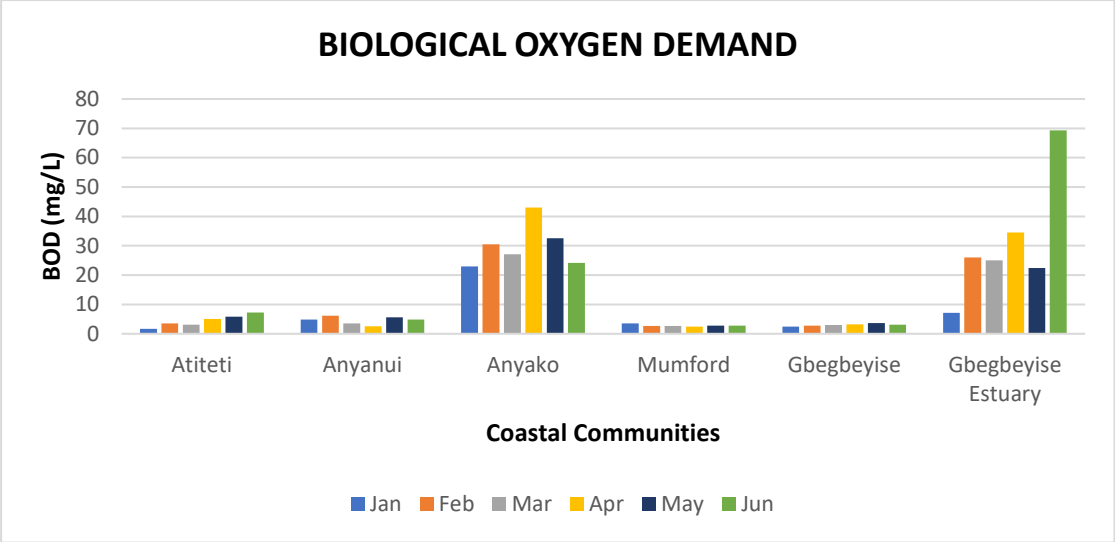

Figure 4.7 Monthly biological oxygen demand (BOD) measurements per community

4.1.8 Nitrate

The mean values of the nitrate concentrations of the water samples for the various communities are presented in Figure 4.8 below.

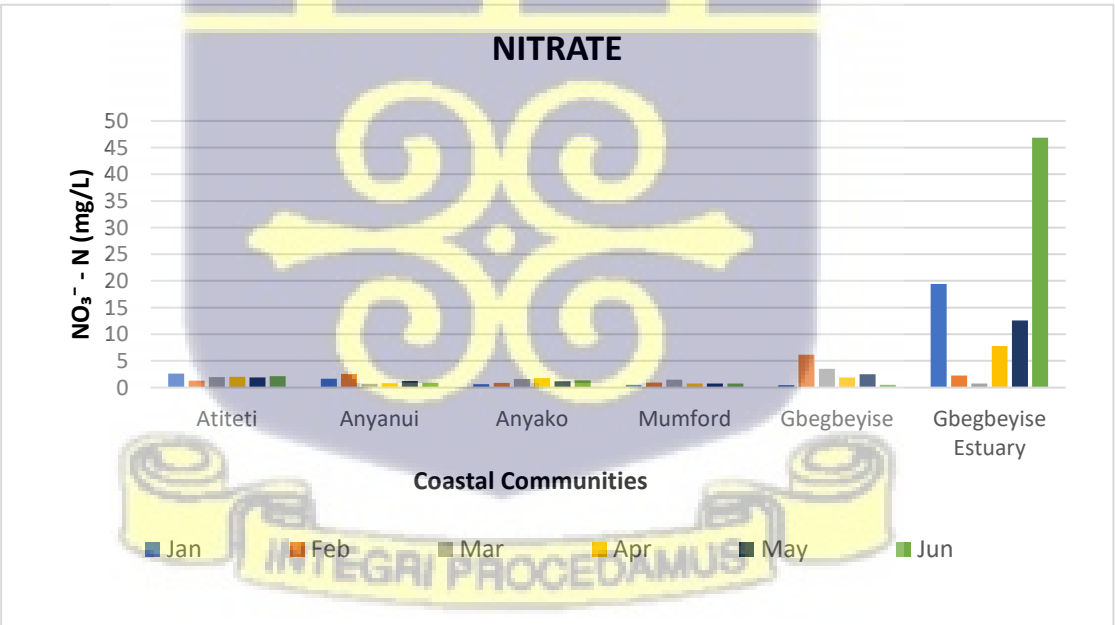

Figure 4.8 Monthly nitrate measurements per community

There were no significant patterns for increase or decrease observed in all seasons. Gbegbeyise Beach and Estuary had the highest nitrate records. At Anyako, Anyanui and Mumford, higher nitrate records were observed mostly in the dry season. Gbegbeyise estuary water samples were the only samples with high nitrate values in the rainy season (Figure 4.8).

4.1.9 Phosphate

The mean values of the concentration of phosphate in the water samples recorded are presented in Figure 4.9 below:

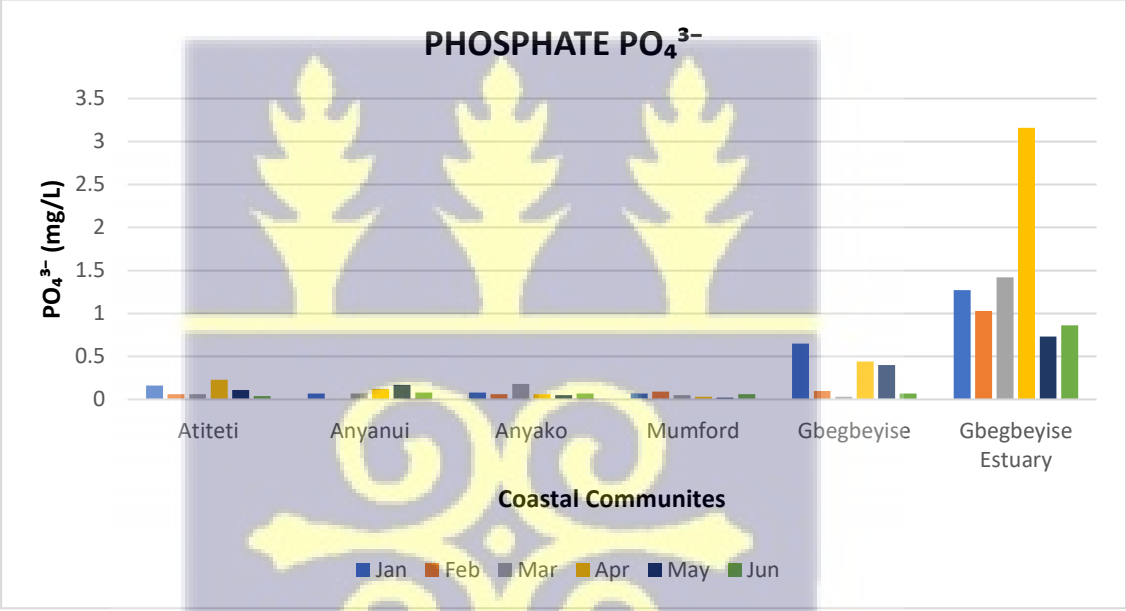

Figure 4.9 Monthly phosphate measurements per community

Atiteti, Anyanui, Gbegbeyise Beach and Gbegbeyise Estuary had higher concentrations recorded in the rainy season while Anyako and Mumford, had higher concentrations in the dry season (Figure 4.9).

4.1.10 Sulphate

The mean values of the sulphate concentrations of the water samples are presented in Figure 4.10 below.

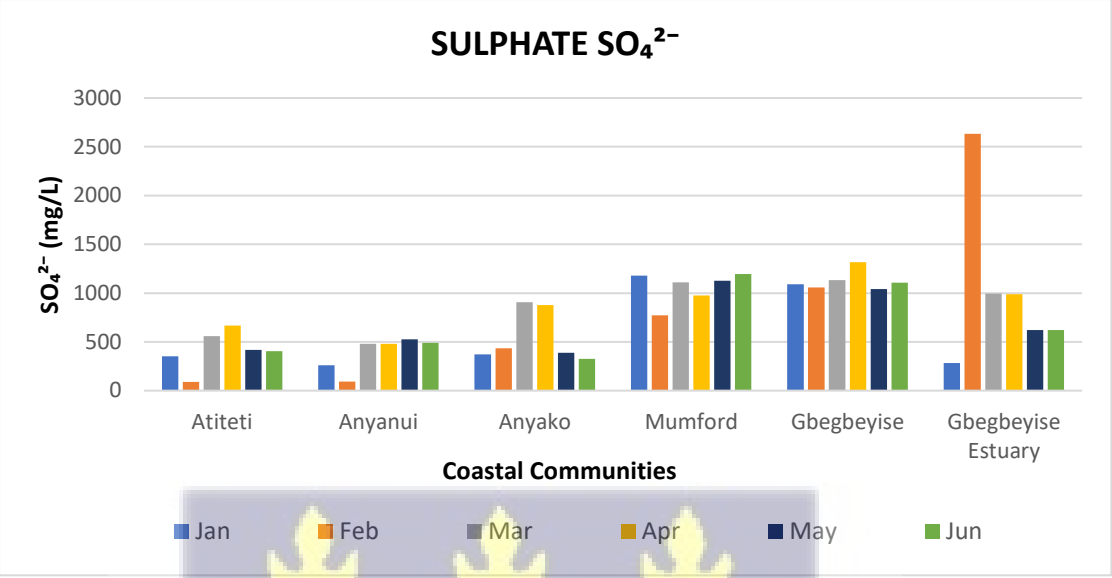

Figure 4.10 Monthly sulphate measurements per community

Atiteti, Anyanui, Mumford and Gbegbeyise beaches had higher concentrations recorded in the rainy season while Anyako Fishing Lagoon and Gbegbeyise's Estuary had higher concentrations in the dry season. Anyako and Atiteti were the only communities that presented seasonal patterns with Atiteti having a decrease in sulphate levels during the rainy season and Anyako having an increase as the dry season progressed and decreased from the onset of the rainy season through the last sampling month in June (Figure 4.10).

4.2 Microbial contamination of water, biota, and sediment samples

4.2.1 Microbial contamination in water

The mean values of the total coliform and Escherichia coli enumerated from the water samples are presented in Figures 4.11 and 4.12 respectively.

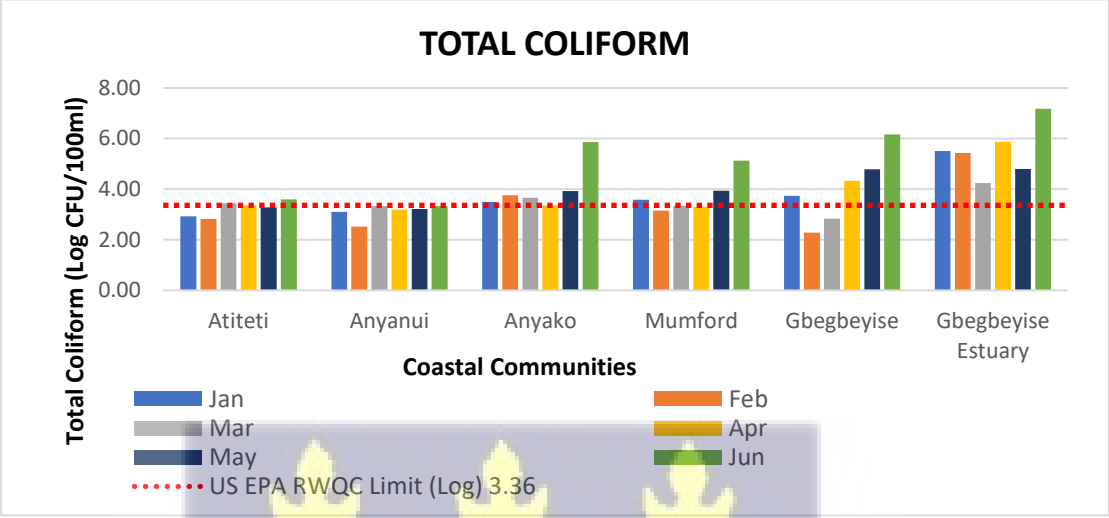

Figure 4.11 Monthly distribution of total coliforms (log CFU/100ml) per community

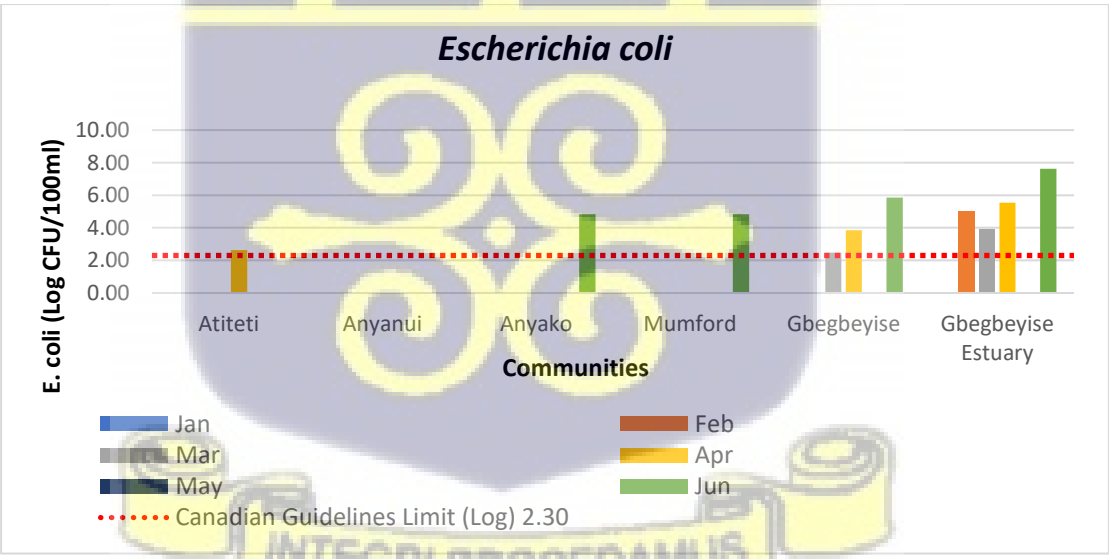

Figure 4.12 Monthly distribution of *Escherichia coli* (log CFU/100ml) per community

Total coliform counts were recorded in all communities during the entire sampling period. The rainy season had relatively higher total coliform counts than the dry season (Figure 4.11).

All communities that had *E. coli* counts irrespective of the seasons, exceeded the 200 *E. coli*/100ml (or Log variant 2.30) No observed adverse effect levels (NOAELs) according to the 2012 Guidelines for Canadian Recreational Water Quality. The rainy season had relatively higher and more occurrences (Figure 4.12).

4.2.2 Microbial contamination load in biota

The total coliform and *Escherichia coli* (*E. coli*) enumerated in the biota samples for all communities in colony-forming units per gram (CFU/g) are presented in Table 4.1. No records were presented for Gbegbeyise Estuary as no biota were found there.

Table 4.1 Coliform (TCC) and *Escherichia coli* (*E. coli*) count in biota samples (mean-standard deviation)

	TCC (CFU/g)	*E. coli* (CFU/g)
Atiteti (Bogue fish – *Boops boops*)		
Jan	-	-
Feb	-	-
Mar	14600 ± 12996.54	0
Apr	5003 ± 5340.51	0
May	-	-
Jun	-	-
Total	9802 ± 10324.78	0
Anyanui (Mangrove oyster - *Crassostrea gasar*)		
Jan	567 ± 513.16	0
Feb	34800 ± 48343.77	0
Mar	59333 ± 37753.59	16000 ± 27712.81
Apr	5723 ± 6673.35	0
May	700 ± 1109.23	220 ± 381.05
Jun	277 ± 247.86	0
Total	16900 ± 31409.52	2703 ± 11305.62
Anyako (Bogue fish – *Boops boops*)		
Jan	1266 ± 1778.58	600 ± 1039.23
Feb	3502900 ± 5878746.66	0
Mar	0	0
Apr	19666667 ± 1530795	6566667 ± 472581.56
May	27 ± 46.19	0
Jun	130083 ± 245393.91	0
Total	3366740 ± 7039652.11	6566667 ± 472581.56
Mumford (*Priacanthus arenatus* and *Chloroscombrus chrysurus*)		
Jan	36367 ± 36435.74	10967 ± 13468.61
Feb	0	0
Mar	-	-
Apr	10367 ± 4670.47	0
May	106133 ± 109083.70	91900 ± 119955.28
Jun	-	-
Total	38217 ± 65403.61	25717 ± 65298.49
Gbegbeyise Beach (Atlantic Ghost Crab/Ocypode)		
Jan	-	-
Feb	-	-
Mar	19000 ± 19056.76	0
Apr	21658 ± 42274.74	7078 ± 14258.49
May	-	-
Jun	5623 ± 7344.16	0
Total	17919 ± 33502.97	4247 ± 11360.26

4.2.3 Total coliforms and *Escherichia coli* in Sediment

The total coliform count and *Escherichia coli* enumerated in the sediment samples in coliform forming units per gram (CFU/g) per community are presented in Table 4.2.

Table 4.2 Total coliform (TCC) and *Escherichia coli* (*E. coli*) count in sediment samples (Mean-Standard Deviation)

	TCC (CFU/g)	*E. coli* (CFU/g)
	Atiteti	
Jan	16 ± 11.40	0
Feb	140 ± 179.86	0
Mar	1784 ± 3922.41	0
Apr	42 ± 69.98	0
May	7 ± 16.33	0
Jun	462 ± 1029.30	0
Total	387 ± 1574.82	0
	Anyanui	
Jan	30 ± 43.59	0
Feb	1220 ± 141.42	0
Mar	1375 ± 1053.59	0
Apr	140 ± 175.78	0
May	33 ± 49.33	0
Jun	10 ± 17.32	5 ± 9.24
Total	364 ± 627.16	1 ± 1.00
	Anyako	
Jan	58 ± 72.28	0
Feb	972 ± 1147.36	0
Mar	1248 ± 2677.66	0
Apr	327 ± 599.26	3 ± 10.33
May	104 ± 238.33	104 ± 238.33
Jun	163 ± 185.14	20 ± 49.03
Total	500 ± 1249.92	21 ± 101.16
	Mumford	
Jan	508 ± 1291.81	0
Feb	1866 ± 3393.09	8 ± 16.69
Mar	1181 ± 4315	0
Apr	47 ± 47.26	0
May	8 ± 7.07	0
Jun	101 ± 200.78	0
Total	832 ± 2665.62	2 ± 8.66
	Gbegbeyise Beach	
Jan	40 ± 38.73	0
Feb	616 ± 754.65	0
Mar	1963 ± 3906.72	2273 ± 3805.72
Apr	701 ± 1691.56	0
May	10 ± 20.00	0
Jun	1371 ± 2833.92	0
Total	758.12 ± 2001.76	284 ± 1455.36
	Gbegbeyise Estuary	
Jan	140 ± 208.09	0
Feb	643 ± 929.16	0
Mar	30 ± 20	0
Apr	107 ± 112.40	0
May	23 ± 32.15	0
Jun	887 ± 685.95	0
Total	305 ± 531.67	0

4.2.4 Distribution of identified bacteria isolated from the biota, sediment, and water samples per community

The percentage of target diarrhoeagenic bacteria (Vibrio species, *Escherichia coli* and Salmonella) and faecal indicators (*Enterococcus faecalis* and *Escherichia coli*) out of the general population of bacteria isolates per component in each community for the entire sampling period, are presented in Figure 4.13.

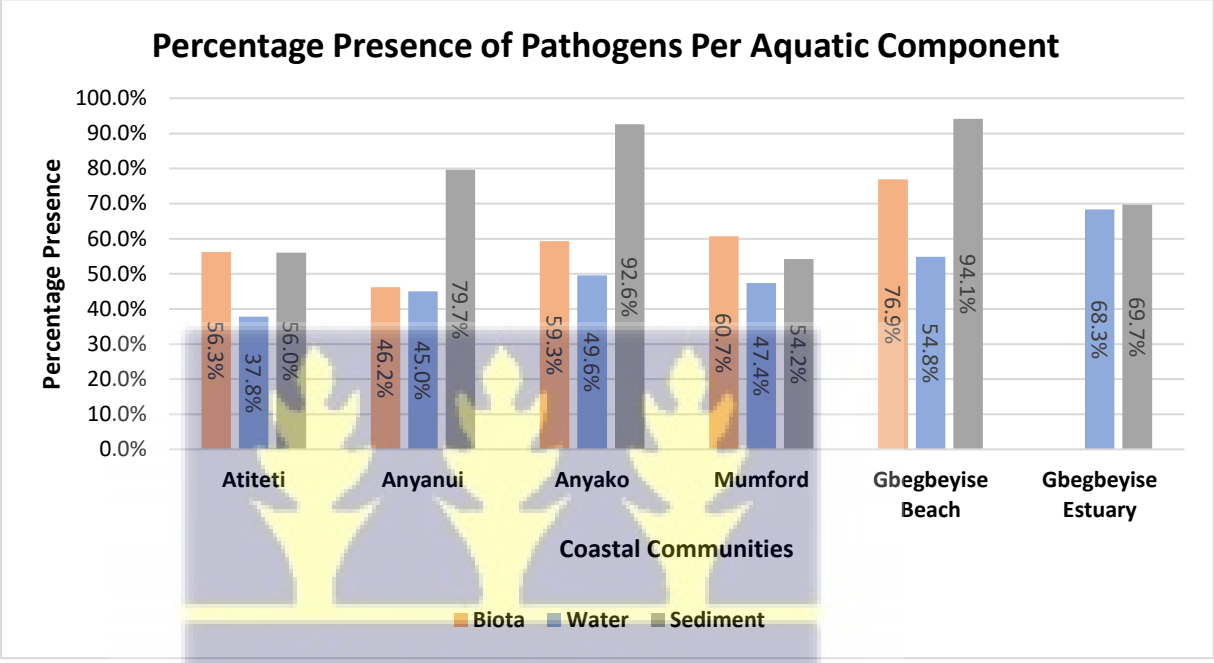

Figure 4.13 Pathogens present per aquatic components per community for the entire sampling period

For all the communities the sediment samples were the most contaminated, the biota samples had the next highest record, and the water samples had the least. The samples from Gbegbeyise were the most laden with pathogens (Fig 4.13).

4.2.5 Distribution of identified bacteria isolated from the biota, sediment, and water samples per community in the dry season

The percentage of target diarrhoeagenic bacteria isolated in each aquatic component per community in the dry season (January to March) are presented in Figure 4.14.

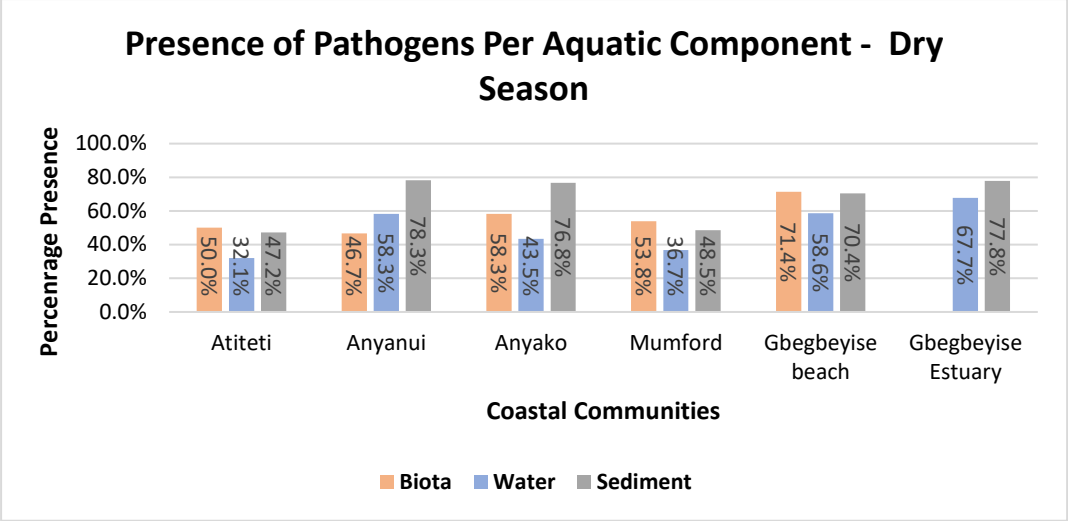

Figure 4.14 Pathogens present per aquatic components per community in the dry season

4.2.6 Distribution of identified bacteria isolated from the biota, sediment, and water samples per community in the rainy season

The percentage of target diarrhoeagenic bacteria isolated in each aquatic component per community in the rainy season (April to June) are presented in Figure 4.15).

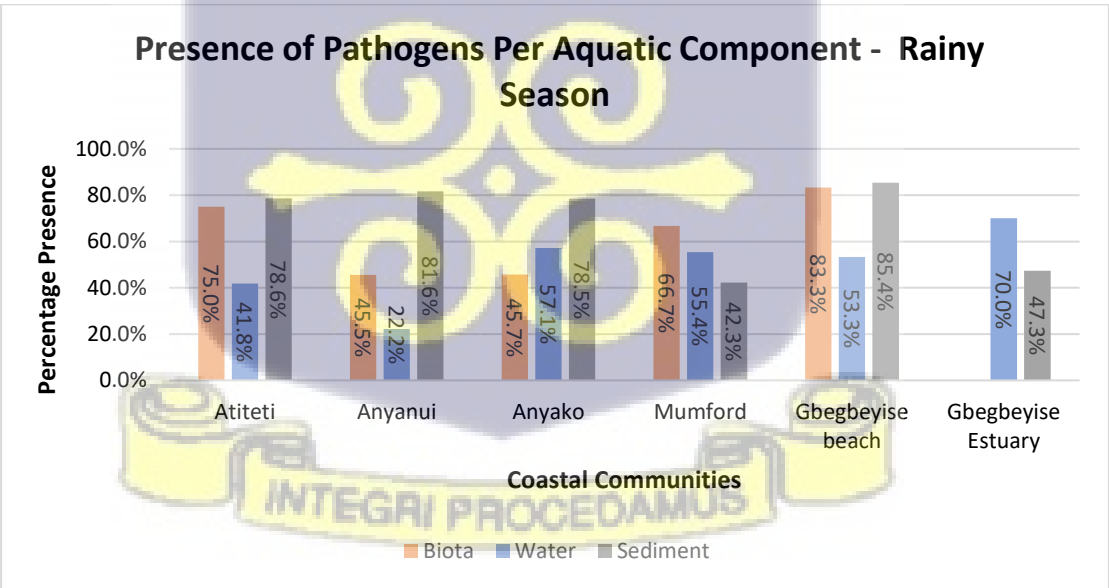

Figure 4.15 Pathogens present per aquatic components per community in the wet season

A comparison of the wet and dry seasons shows more pathogens were isolated in the rainy season than in the dry season

4.3 Analysis of water quality status based on the European Union 95th-percentile rating

The status of the water surrounding the coastal communities based on the upper European Union 95-percentile evaluation of the log10 normal probability density of *Escherichia coli* are presented in Figures 4.16 to 4.21.

Keys; ≤ 250 = excellent; ≤ 500 good or satisfactory; >500= poor

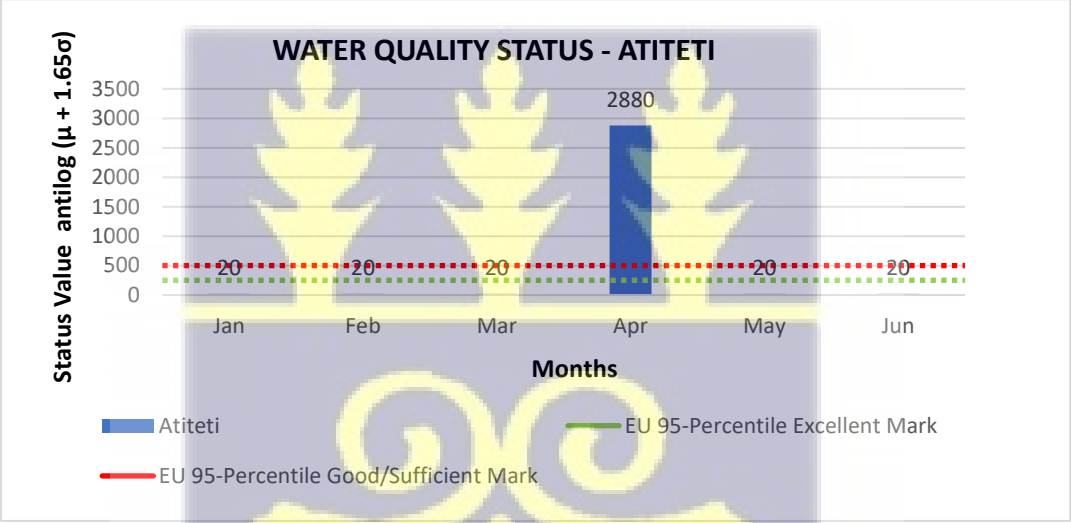

Figure 4.16 Atiteti water quality status rating based on the upper 95-percentile evaluation score

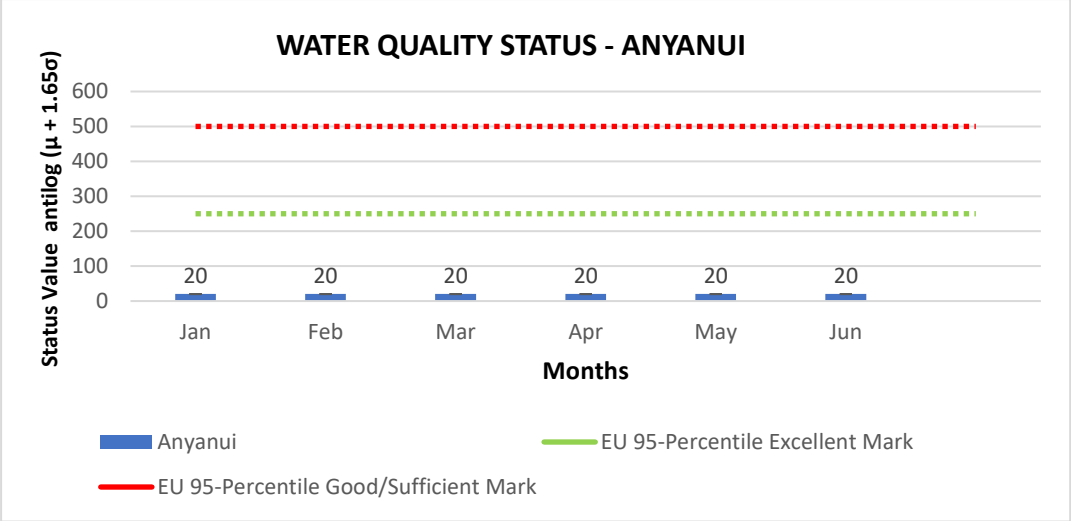

Figure 4.17 Anyanui water quality status rating based on the upper 95-percentile evaluation score

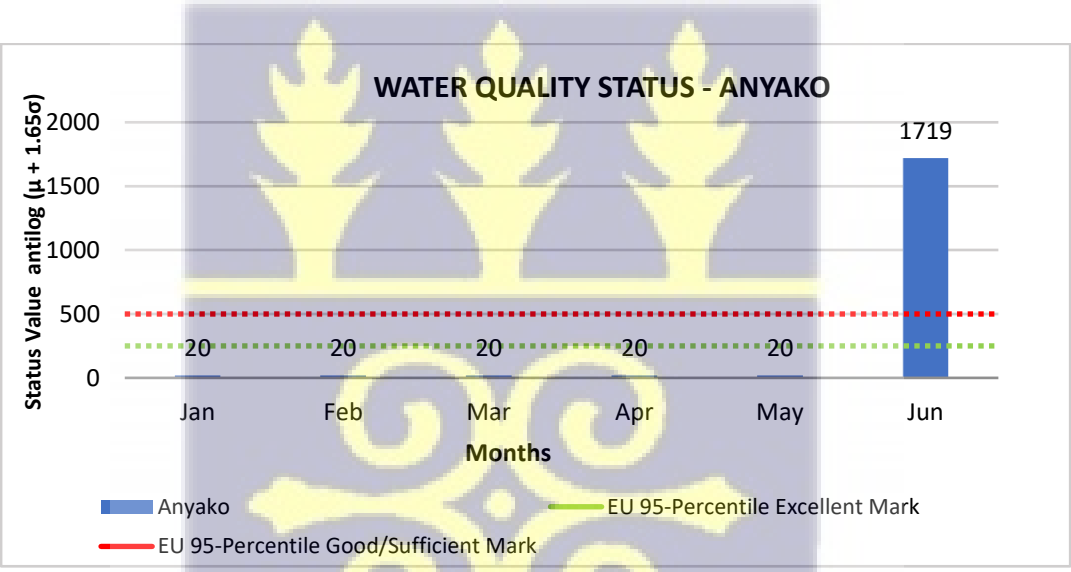

Figure 4.18 Anyako water quality status rating based on the upper 95-percentile evaluation score

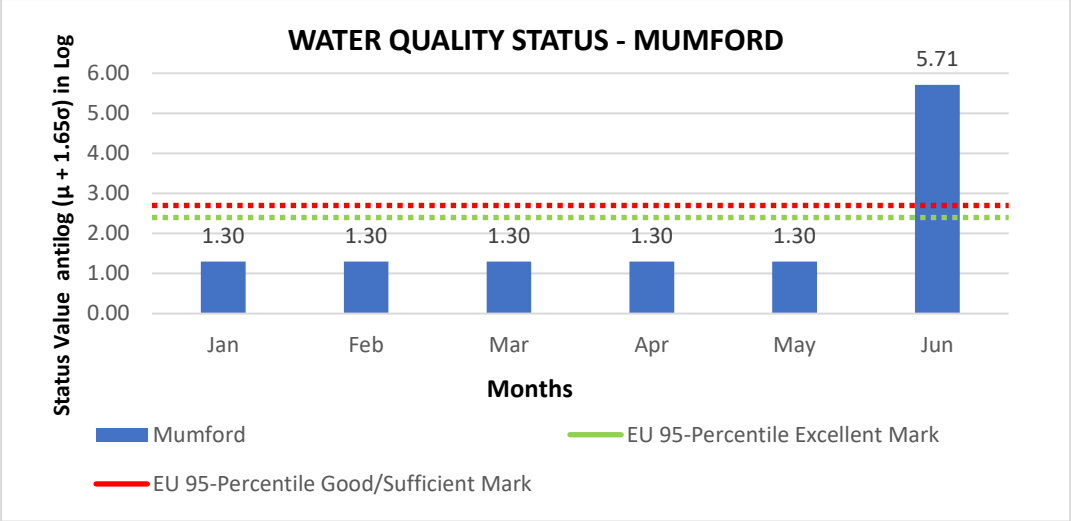

Figure 4.19 Mumford water quality status rating based on the upper 95-percentile evaluation score

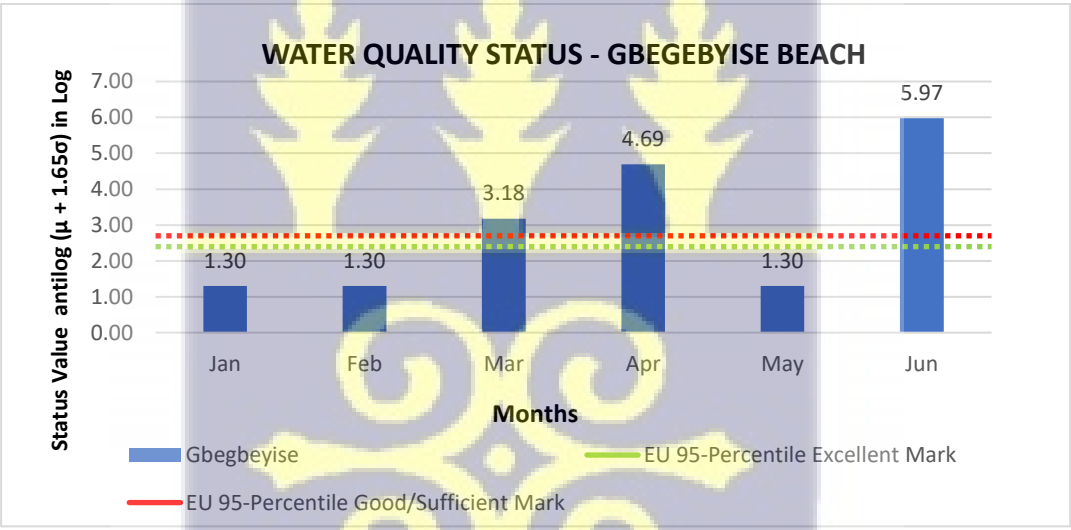

Figure 4.20 Gbegbeyise beach water quality status rating based on the upper 95-percentile evaluation score

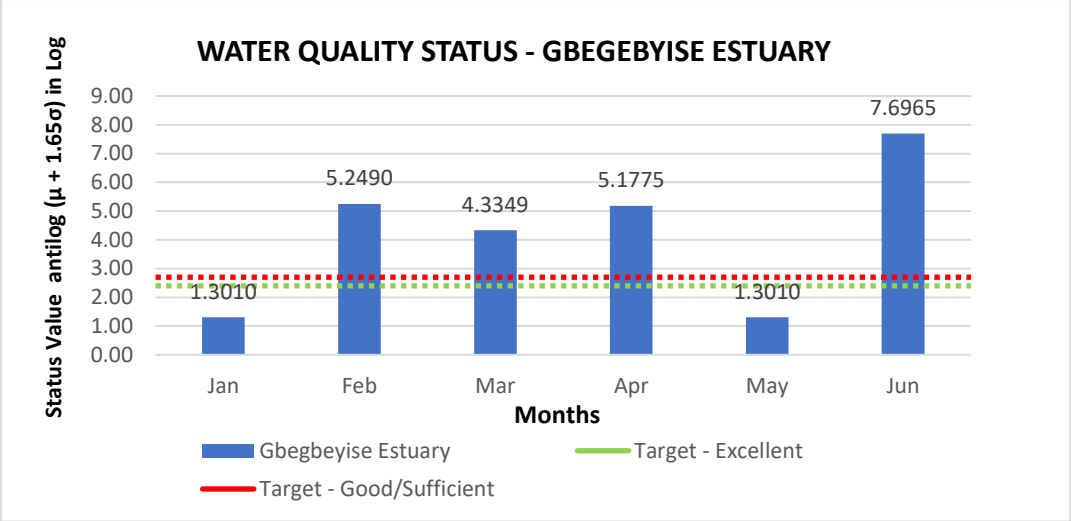

Figure 4.21 Gbegbeyise estuary water quality status rating based on the upper 95-percentile evaluation score

Based on this rating, Gbegbeyise Estuary was the most contaminated with the faecal indicator *Escherichia coli* hence the least healthy. Gbegbeyise Beach came in second, then Mumford, Atiteti and Anyako. Anyanui was the healthiest with no faecal coliforms enumerated.

4.4 Inter-Correlation between physiochemical parameters and coliform in the water Samples

The associations between the faecal indicator bacteria and physicochemical parameters of the water samples were determined by Pearson's correlation coefficient significant at a 95% confidence interval ($p < 0.05$). The associations have been presented in Table 4.3 to 4.20.

Key

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

- Cannot be computed because at least one of the variables is constant.

Atiteti

Table 4.3 Interactions Between Physicochemical Parameters and Bacterial Contaminants in Water Samples for the Entire Sampling Period for Atiteti

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	0.568**	1										
EC	0.048	0.25	1									
TDS	0.079	0.257	0.998**	1								
Sal	0.041	0.243	0.999**	0.998**	1							
DO	0.058	-0.274	-.374	-.368	-0.368	1						
BOD	0.031	0.433	0.103	0.098	0.09	-0.393	1					
NO_3^-	-0.163	-0.049	-0.204	-0.212	-0.215	0.075	0.466	1				
PO_4^{3-}	-0.037	-0.141	-0.128	-0.124	-0.126	-0.236	-0.196	-0.069	1			
SO_4^{2-}	-0.076	.386	-0.107	-0.118	-0.115	-0.245	0.203	0.015	0.172	1		
TC	-0.135	0.267	-0.021	-0.026	-0.026	-0.115	.675**	0.305	-0.076	0.277	1	
E. coli	0.015	0.03	-0.237	-0.232	-0.237	-0.367	-0.004	-0.234	0.148	0.357	-0.043	1

Table 4.4 Correlations Between Measured Parameters from January to March (Dry Season) - Atiteti

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	0.750**	1										
EC	0.729**	0.422	1									
TDS	0.738**	0.425	0.997**	1								
Sal	0.734**	0.424	0.999**	0.998**	1							
DO	-0.300	0.084	-0.492	-0.499	-0.495	1						
BOD	0.635**	0.452	0.499	.486	0.498	0.029	1					
NO_3^-	-0.461	-0.288	-0.266	-0.282	-0.268	0.017	-0.414	1				
PO_4^{3-}	-0.23	-0.275	-0.205	-0.198	-0.203	0.082	-0.407	0.377	1			
SO_4^{2-}	-0.149	0.362	-0.108	-0.124	-0.113	0.393	-0.253	-0.018	-0.075	1		
TCC	0.098	0.439	-0.222	-0.222	-0.222	0.475	-0.069	-0.42	0.044	0.623**	1	
E. coli	-	-	-	-	-	-	-	-	-	-	-	1

Table 4.5 Correlations Between Measured Parameters from April to June (Wet Season) - Atiteti

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	0.781**	1										
EC	-0.700**	-0.451	1									
TDS	-0.692**	-0.442	0.999**	1	-0.692**							
Sal	-0.706**	-0.453	0.999**	0.999**	1	-0.706**						
DO	-0.347	-0.140	0.067	0.05	0.064	1	-0.347					
BOD	0.152	0.530*	-0.254	-0.247	-0.263	0.162	1	0.152				
NO_3^-	0.155	0.347	-0.185	-0.182	-0.204	0.341	0.818**	1	0.155			
PO_4^{3-}	0.273	-0.060	-0.131	-0.122	-0.127	-0.633**	-0.338	-0.446	1			
SO_4^{2-}	0.369	0.122	-0.447	-0.432	-0.449	-0.695**	0.210	0.040	0.530*	1		
TCC	-0.113	0.200	-0.137	-0.134	-0.139	0.325	0.673**	0.509*	-0.184	0.133	1	
E. coli	0.136	-0.133	-0.49	-0.486	-0.478	-0.493	-0.160	-0.324	0.176	0.615**	-0.132	1

Anyanui

Table 4.6 Interactions Between Physicochemical Parameters and Bacterial Contaminants in Water Samples for the Entire Sampling Period for Anyanui

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	-0.198	1										
EC	0.085	0.371	1									
TDS	.683**	-0.308	0.414	1								
Sal	.700**	-0.401	0.311	.992**	1							
DO	.580*	-0.152	-0.016	0.363	0.357	1						
BOD	0.119	0.148	0.208	0.102	0.109	-.531*	1					
NO_3^-	0.054	0.159	.711**	0.429	0.381	-0.491	.719**	1				
PO_4^{3-}	-0.149	-0.075	-.760**	-.574*	-.510*	-0.121	-0.275	-.612**	1			
SO_4^{2-}	-0.007	-0.193	-.884**	-0.482	-0.411	0.284	-.515*	-.916**	.812**	1		
TCC	-0.002	0.019	-0.341	-0.24	-0.221	0.185	-0.266	-0.462	0.331	0.438	1	
E. coli	-	-	-	-	-	-	-	-	-	-	-	1

Table 4.7 Correlations Between Measured Parameters from January to March (Dry Season) - Anyanui

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	-0.552	1										
EC	-0.628	0.132	1									
TDS	.787*	-0.556	-0.033	1								
Sal	.803**	-0.602	-0.058	.998**	1							
DO	.756*	-0.262	-.941**	0.244	0.267	1						
BOD	-0.253	-0.144	.886**	0.366	0.344	-.700*	1					
NO_3^-	-0.282	-0.112	.913**	0.34	0.315	-.758*	.970**	1				
PO_4^{3-}	-0.17	0.415	-0.642	-.719*	-.705*	0.419	-.886**	-.886**	1			
SO_4^{2-}	0.338	0.118	-.932**	-0.296	-0.277	.778*	-.985**	-.976**	.855**	1		
TCC	C	0.161	-0.595	-0.249	-0.236	0.392	-.704*	-.693*	.692*	.702*	1	
E. coli	-	-	-	-	-	-	-	-	-	-	-	1

Table 4.8 Correlations Between Measured Parameters from April to June (Wet Season) - Anyanui

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	.757*	1										
EC	-0.295	-.772*	1									
TDS	-0.296	-.773*	0.999**	1								
Sal	-0.258	-.751*	.995**	.995**	1							
DO	-.735*	-.945**	.723*	.725*	.694*	1						
BOD	0.525	.924**	-.943**	-.944**	-.925**	-.906**	1					
NO_3^-	.839**	.902**	-0.532	-0.535	-0.491	-.897**	.764*	1				
PO_4^{3-}	.733*	0.593	0.019	0.017	0.05	-0.537	0.278	.775*	1			
SO_4^{2-}	.903**	.941**	-0.565	-0.566	-0.527	-.930**	.789*	.957**	.733*	1		
TCC	-0.105	0.101	-0.131	-0.129	-0.155	0.121	0.06	-0.055	-0.003	-0.077	1	
E. coli	-	-	-	-	-	-	-	-	-	-	-	1

Anyako

Table 4.9 Interactions Between Physicochemical Parameters and Bacterial Contaminants in Water Samples for the Entire Sampling Period for Anyako

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	-0.397	1										
EC	0.412	-.589**	1									
TDS	.650**	-.896**	.694**	1								
Sal	.621**	-.824**	.736**	.954**	1							
DO	-0.024	0.008	0.154	0.035	0.059	1						
BOD	0.49	-0.36	0.494	.529**	.568**	-.501**	1					
NO_3^-	.647**	-0.436	0.372	.615**	.637**	0.08	0.463	1				
PO_4^{3-}	0.196	0.006	0.114	0.083	0.108	0.23	0.034	0.125	1			
SO_4^{2-}	.728**	-0.11	0.369	0.428	0.485	0.112	0.431	.569**	0.206	1		
TC	-0.034	-0.122	-0.026	0.064	0.046	0.191	-0.305	0.257	-0.062	-0.223	1	
E. coli	0.032	-0.158	-0.04	0.068	0.049	-0.01	-0.174	-0.029	0.00	-0.179	-0.062	1

Table 4.10 Correlations Between Measured Parameters from January to March (Dry Season) - Anyako

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	-.723**	1										
EC	.936**	-.765**	1									
TDS	.852**	-.935**	.913**	1								
Sal	.882**	-.911**	.944**	.993**	1							
DO	.525**	0.062	0.464	0.178	0.257	1						
BOD	0.351	-.645**	0.48	.583**	.567**	-0.322	1	0.351				
NO_3^-	.804**	-.556**	.856**	.729**	.768**	.620**	0.377	1	.804**			
PO_4^{3-}	0.308	-0.113	0.378	0.204	0.254	0.248	0.33	0.373	1			
SO_4^{2-}	.778**	-0.426	.731**	.610**	.648**	.733**	-0.022	.784**	0.276	.778**		
TCC	0.097	-0.217	0.186	0.24	0.206	-0.112	0.381	0.188	-0.219	-0.024	1	
E. coli	-	-	-	-	-	-	-	-	-	-	-	1

Table 4.11 Correlations Between Measured Parameters from April to June (Wet Season) - Anyako

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	.806**	1										
EC	-0.039	-0.243	1									
TDS	0.366	0.324	.525**	1								
Sal	0.139	0.274	.506**	.661**	1							
DO	-.810**	-.695**	-0.048	-0.433	-0.356	1						
BOD	.567**	.576**	0.356	.690**	.603**	-.781**	1					
NO_3^-	0.47	.620**	-0.228	0.061	0.175	-.616**	0.346	1				
PO_4^{3-}	0.195	0.052	-0.12	0.011	-0.241	0.177	-0.191	-0.368	1			
SO_4^{2-}	.730**	.684**	0.222	.653**	.550**	-.792**	.838**	.541**	0.052	1		
TCC	-0.118	0.037	-0.177	-0.291	-0.185	0.402	-.550	0.247	-0.043	-0.295	1	
E. coli	-0.009	-0.224	-0.178	-0.179	-0.132	0.021	-0.356	-0.203	0.327	-0.234	-0.123	1

Mumford

Table 4.12 Interactions Between Physicochemical Parameters and Bacterial Contaminants in Water Samples for the Entire Sampling Period for Mumford

	Temp	**pH**	**EC**	**TDS**	**Sal**	**DO**	**BOD**	**NO_3^-**	**PO_4^{3-}**	**SO_4^{2-}**	**TC**	*E. coli*
Temp	1											
pH	0.244	1										
EC	-0.314	-.632**	1									
TDS	-0.304	-0.328	0.296	1								
Sal	-0.119	-0.442	0.382	.500**	1							
DO	-.622**	-.526**	.527**	0.135	0.288	1						
BOD	-0.01	0.375	-0.341	0.094	-0.095	-0.382	1					
NO_3^-	0.134	-0.258	0.204	0.107	0.234	0.122	-0.169	1				
PO_4^{3-}	-0.479	-0.334	0.156	0.279	0.224	0.463	0.015	0.41	1			
SO_4^{2-}	0.264	0.143	-0.429	-0.132	-0.23	-0.308	0.295	-0.169	-0.018	1		
TC	-0.06	-0.079	-0.021	-0.073	-0.023	-0.02	0.021	-0.301	-0.184	-0.044	1	
E. coli	-0.065	-0.096	-0.009	-0.069	-0.022	-0.011	0.009	-0.296	-0.176	-0.043	.999**	1

Table 4.13 Correlations Between Measured Parameters from January to March (Dry Season) - Mumford

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	0.152	1										
EC	-0.308	-.616**	1									
TDS	-0.288	0.172	0.06	1								
Sal	-0.001	0.095	-0.123	0.387	1							
DO	-.686**	-0.469	0.495	0.063	0.198	1						
BOD	0.176	.684**	-.513*	-0.028	-0.273	-0.46	1					
NO_3^-	0.182	-.547**	0.123	-0.215	-0.017	0.14	-0.482	1				
PO_4^{3-}	-0.496	-0.008	-0.062	-0.097	-0.057	0.468	-0.175	-0.085	1			
SO_4^{2-}	.591**	0.205	-0.45	-0.122	-0.126	-.520*	.515*	-0.305	-0.154	1		
TCC	0.142	0.433	-0.396	.533**	0.49	-0.244	0.256	-0.073	-0.099	0.142	1	
E. coli	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.14 Correlations Between Measured Parameters from April to June (Wet Season) - Mumford

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	0.405	1										
EC	-0.434	-.826**	1									
TDS	-0.492	-.814**	.993**	1								
Sal	-0.446	-.818**	.991**	.987**	1							
DO	-.577**	-.720**	.659**	0.456	.637**	1						
BOD	-0.279	0.25	-0.188	-0.178	-0.156	-0.085	1					
NO_3^-	0.177	-0.194	0.221	0.215	0.238	0.199	-0.207	1				
PO_4^{3-}	-0.271	-.627**	.566**	.565**	.580**	.649**	-0.121	.682**	1			
SO_4^{2-}	-.561**	-0.029	-0.059	-0.003	-0.068	0.355	0.008	-0.176	0.269	1		
TCC	-0.13	-0.117	0.041	0.024	0.059	-0.058	0.112	-0.283	-0.253	-0.14	1	
E. coli	-0.137	-0.134	0.057	0.04	0.074	-0.045	0.095	-0.279	-0.243	-0.134	0.999**	1

Gbegbeyise Beach

Table 4.15 Interactions Between Physicochemical Parameters and Bacterial Contaminants in Water Samples for the Entire Sampling Period for Gbegbeyise Beach

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TC	*E. coli*
Temp	1											
pH	0.1	1										
EC	0.116	-0.033	1									
TDS	0.112	0.069	.966**	1								
Sal	0.007	-0.475	0.481	0.266	1							
DO	-.654**	-0.024	0.214	0.148	0.32	1						
BOD	0.158	0.05	-0.136	-0.234	0.289	0.136	1					
NO_3^-	0.088	-0.29	0.248	0.179	0.376	0.232	0.058	1				
PO_4^{3-}	0.107	0.327	-.585**	-.553**	-0.461	-0.166	0.082	-0.199	1			
SO_4^{2-}	0.141	-0.165	-0.326	-0.337	0.006	-0.208	0.055	0.037	-0.038	1		
TC	-0.191	-0.092	-0.121	-0.14	-0.002	0.149	0.132	-0.15	-0.054	-0.201	1	
E. coli	-0.194	-0.099	-0.121	-0.14	-0.003	0.147	0.124	-0.148	-0.058	-0.198	0.999**	1

Table 4.16 Correlations Between Measured Parameters from January to March (Dry Season) – Gbegbeyise Beach

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	E. coli
Temp	1											
pH	-0.189	1										
EC	-0.091	-.728**	1									
TDS	-0.299	0.027	0.48	1								
Sal	0.071	-.927**	.861**	0.047	1							
DO	-.752**	-0.226	0.325	0.196	0.288	1						
BOD	0.237	-0.364	0.236	-0.088	0.304	0.077	1					
NO_3^-	-0.418	-.538**	.650**	0.213	.662**	.636**	0.41	1				
PO_4^{3-}	-0.09	.640**	-0.403	-0.26	-.520*	-0.145	-0.295	-0.384	1			
SO_4^{2-}	0.302	-0.152	0.003	-0.118	0.138	0.078	0.228	0.082	-0.093	1		
TCC	-0.044	0.446	-.531**	0.191	-.582**	-0.2	-0.214	-0.35	-0.08	0.048	1	
E. coli	0.478	-0.204	0.144	-0.072	0.216	-0.349	0.367	0.184	-0.17	.550**	-0.064	1

Table 4.17 Correlations Between Measured Parameters from April to June (Wet Season) – Gbegbeyise Beach

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	E. coli
Temp	1											
pH	0.474	1										
EC	0.083	0.267	1									
TDS	0.067	0.251	.995**	1								
Sal	0.084	0.253	.999**	.995**	1							
DO	-.549**	0.134	0.351	0.338	0.344	1						
BOD	0.455	0.244	-0.013	-0.02	-0.009	0.009	1					
NO_3^-	.776**	.545**	-0.066	-0.071	-0.071	-0.356	0.436	1				
PO_4^{3-}	0.28	0.055	-.674**	-.677**	-.674**	-0.237	0.28	0.144	1			
SO_4^{2-}	0.133	-0.276	-0.372	-0.351	-0.375	-.553**	-0.298	0.31	-0.043	1		
TCC	-0.213	-0.187	-0.086	-0.095	-0.086	0.193	0.099	-0.259	-0.088	-0.298	1	
E. coli	-0.219	-0.193	-0.088	-0.097	-0.089	0.191	0.09	-0.264	-0.092	-0.292	0.999**	1

Gbegbeyise Estuary

Table 4.18 Interactions Between Physicochemical Parameters and Bacterial Contaminants in Water Samples for the Entire Sampling Period for Gbegbeyise Estuary

	Temp	**pH**	**EC**	**TDS**	**Sal**	**DO**	**BOD**	**NO_3^-**	**PO_4^{3-}**	**SO_4^{2-}**	**TC**	***E. coli***
Temp	1											
pH	-0.439	1										
EC	-.652**	.692**	1									
TDS	-.582*	.641**	.982**	1								
Sal	-.695**	.759**	.877**	.775**	1							
DO	-.621**	0.143	0.164	0.015	0.494	1						
BOD	0.304	0.088	-0.285	-0.156	-.504*	-.617**	1					
NO_3^-	0.097	0.286	-0.119	-0.123	-0.054	-0.051	0.435	1				
PO_4^{3-}	-0.474	-0.467	-0.068	-0.043	-0.197	0.222	-0.037	-0.205	1			
SO_4^{2-}	.510*	-.560*	-0.249	-0.156	-0.423	-0.246	-0.023	-0.292	0.03	1		
TC	0.278	0.254	-0.296	-0.242	-0.318	-0.335	.747**	.784**	-0.213	-0.18	1	
E. coli	0.255	0.108	-0.2	-0.166	-0.221	-0.235	0.487	.963**	-0.158	-0.122	.787**	1

Table 4.19 Correlations Between Measured Parameters from January to March (Dry Season) – Gbegbeyise Estuary

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	-.974**	1										
EC	-.835**	.899**	1									
TDS	.878**	-.858**	-0.638	1								
Sal	-.962**	.995**	.932**	-.818**	1							
DO	-.862**	.925**	.838**	-.698*	.927**	1						
BOD	.982**	-.997**	-.901**	.872**	-.993**	-.903**	1					
NO_3^-	-.927**	.967**	.895**	-.798**	.967**	.915**	-.956**	1				
PO_4^{3-}	-0.034	0.001	0.18	-0.051	0.044	-0.184	-0.058	-0.107	1			
SO_4^{2-}	.747*	-.691*	-0.518	.866**	-0.644	-0.434	.714*	-0.61	-0.159	1		
TCC	-0.516	0.621	0.522	-0.339	0.630	0.441	-0.576	0.643	-0.425	0.05	1	
E. coli	0.600	-0.529	-0.522	0.604	-0.511	-0.217	0.565	-0.451	-0.325	.878**	0.301	1

Table 4.20 Correlations Between Measured Parameters from April to June (Wet Season) – Gbegbeyise Estuary

	Temp	pH	EC	TDS	Sal	DO	BOD	NO_3^-	PO_4^{3-}	SO_4^{2-}	TCC	*E. coli*
Temp	1											
pH	0.186	1										
EC	-0.627	0.603	1									
TDS	-0.634	0.599	0.999**	1								
Sal	-0.534	.678*	.986**	.985**	1							
DO	-.946**	-0.363	0.473	0.479	0.367	1						
BOD	.886**	-0.209	-.899**	-.902**	-.829**	-.804**	1					
NO_3^-	0.649	0.017	-0.383	-0.389	-0.338	-0.501	0.489	1				
PO_4^{3-}	-0.607	-.876**	-0.222	-0.215	-0.332	.730*	-0.221	-0.3	1			
SO_4^{2-}	-0.653	-.850**	-0.166	-0.157	-0.271	.752*	-0.27	-0.328	.995**	1		
TCC	.789*	0.059	-0.625	-0.627	-0.554	-.693*	.770*	.785*	-0.33	-0.365	1	
E. coli	0.608	-0.046	-0.398	-0.404	-0.36	-0.452	0.475	.997**	-0.229	-0.256	.773*	1

4.5 Principal component analysis of the measured parameters per component

Principal component analysis was conducted for variables (physicochemical and microbial parameters) considered for the coastal aquatic waters of all six sampling areas. The analysis carried out per community reduced the entire data depicting commonalities to identify variables (key contaminants) that influenced the data set and possible sources. The principal components selected were those with Eigenvalues above 1 which contributes to a greater percentage of the variance observed in the data set. Each component was then interpreted by sorting out variables that are highly correlated based on how farther they are from zero. In this study correlations above 0.5 were sorted out. The communalities for each parameter are spelt out in the last column of each table which shows how much the selected factors best explain the parameter in view and the closer to 1 the communality value is, the better that parameter is explained.

Principal Component Analysis of Atiteti Beach Water

In Atiteti four principal components with Eigenvalues above 1 accounted for 76.1% of the total variance observed (Table 4.21). For PCA 1 which accounted for a 28.7% variance had heavy loadings of salinity, conductivity and total dissolved solids showed strong correlations. PCA 2 which accounted for 20% variance had heavy loadings of salinity BOD, nitrate, and total coliform. PCA 3 explained 15.1% of the variance and was strongly correlated with *E. coli*, phosphate, Nitrate, and decreasing DO in the data set. PCA 4 explained up to 12.2% variance was mostly increased by temperature and pH.

Table 4.21 Principal Component Analysis of Atiteti Beach Water

	---------- Component ----------				
Parameter	**1**	**2**	**3**	**4**	**Communalities**
Salinity	**0.990**	-0.048	-0.079	-0.002	0.985
EC	**0.989**	-0.037	-0.077	0.004	0.985
TDS	**0.984**	-0.049	-0.081	0.027	0.983
BOD	0.113	**0.878**	0.074	0.145	0.849
T. Col	-0.018	**0.819**	0.069	-0.003	0.678
NO_3^-	-0.221	**0.695**	0.273	-0.229	0.627
E. coli	-0.208	-0.139	**0.764**	0.086	0.649
DO	-0.493	-0.205	**-0.668**	0.063	0.734
SO_4^{2-}	-0.122	0.287	**0.642**	0.170	0.561
PO_4^{3-}	-0.058	-0.204	**0.534**	-0.243	0.385
Temp	-0.088	-0.224	-0.121	**0.902**	0.821
pH	0.160	0.277	0.151	**0.812**	0.878
Eigenvalue	3.453	2.403	1.814	1.466	
% of variance explained	28.773	20.025	15.113	12.214	
% of cumulative	28.773	48.798	63.911	76.125	

Extraction Method: Principal Component Analysis. Rotation Method: Oblimin with Kaiser Normalization. Rotation converged in 8 iterations.

Principal Component Analysis of Anyanui Mangrove Swamp Water

Three components that best explained 79.8% variance were extracted for this sampling area (Table 4.22) PCA 1 had heavy loadings of BOD nitrate and with decreasing DO levels with the three parameters showing strong correlations. PCA 1 explained 42.1% of the variance. PCA 2 had heavy loadings of DO, salinity, TDS, temperature and decreasing pH. This component accounted for 26% of the variance. Component 3 was heavily loaded on salinity, TDS, temperature, and dissolved oxygen with decreasing pH. PCA 3 was heavily loaded on EC, pH with decreasing sulphate and phosphate. Component 3 accounted for up to 11.7% variance.

Table 4.22 Principal Component Analysis of Anyanui Mangrove Swamp Water

	---------- Component ----------			
Parameter	**1**	**2**	**3**	**Communalities**
BOD	**0.842**	0.002	-0.042	0.692
DO	**-0.829**	**0.546**	0.182	0.895
NO_3^-	**0.758**	0.138	0.403	0.956
T.Col	-0.488	-0.146	-0.137	0.332
Salinity	0.099	**0.946**	0.068	0.946
TDS	0.07	**0.911**	0.193	0.942
Temp	-0.173	**0.824**	-0.056	0.682
EC	0.11	0.099	**0.905**	0.924
PO_4^{3-}	-0.145	-0.350	**-0.711**	0.787
pH	-0.155	**-0.584**	**0.676**	0.662
SO_4^{2-}	-0.51	-0.157	**-0.668**	
Eigenvalue	4.627	2.859	1.291	
% of variance explained	42.06	25.993	11.736	
% of cumulative	42.06	68.053	79.789	

Extraction Method: Principal Component Analysis. Rotation Method: Oblimin with Kaiser Normalization. Rotation converged in 20 iterations.

Principal Component Analysis of Anyako Lagoon Water

Four components were extracted for this sampling area accounting for a total of 76.8% of the variance observed in the entire dataset (Table 4.23). PCA 1 which explained 41.5% of the variance strongly correlated with TDS and salinity conductivity, nitrate, temperature, and BOD and decreasing pH. component 2 which explained 13.8% variance strongly correlated with total coliform and decreasing BOD accounting. Component 3 accounting for 12.3% of the variance strongly correlated with DO and phosphate. Component 4 which accounted for 9.3% of the variance in the data was influenced mostly by increasing *E. coli* count.

Table 4.23 Principal Component Analysis of Anyako Lagoon Water

	---------- Component ----------				
Parameter	**1**	**2**	**3**	**4**	**Communalities**
TDS	**0.988**	0.035	-0.019	0.073	0.946
Salinity	**0.967**	0.007	0.021	0.027	0.930
pH	**-0.939**	-0.151	0.180	-0.305	0.877
EC	**0.758**	-0.033	0.080	0.052	0.590
NO_3^-	**0.655**	0.160	0.128	-0.390	0.696
Temp	**0.612**	-0.207	0.249	-0.284	0.708
BOD	**0.533**	**0.531**	-0.320	-0.299	0.863
T.Col	0.164	**0.894**	-0.104	-0.195	0.806
DO	0.003	0.498	**-0.729**	0.090	0.783
PO_4^{3-}	-0.002	-0.178	**0.718**	0.038	0.545
E. coli	0.196	-0.143	0.113	**0.818**	0.660
SO_4^{2-}	0.338	-0.314	0.418	-0.497	0.814
Eigenvalue	4.975	1.656	1.473	1.115	
% of variance explained	41.457	13.799	12.272	9.289	
% of cumulative	41.457	55.252	67.528	76.817	

Extraction Method: Principal Component Analysis. Rotation Method: Oblimin with Kaiser Normalization. Rotation converged in 24 iterations.

Principal Component Analysis of Mumford Beach Water

In Mumford, four components were extracted which explained 74.3% of the variance observed in the dataset (Table 4.24). Principal component 1 contributed to a 33.8% variance with heavy loadings of phosphate, dissolved oxygen and decreasing temperature. Component 2 contributed to 18.6% of the variance and was heavily loaded on total coliform and *E. coli*. Component 3 contributed to 11.9% of the variance and was heavily loaded on BOD and sulphate. Component 4 which contributed to 10.1% of the variance was heavily loaded on decreasing salinity and TDS.

Table 4.24 Principal Component Analysis of Mumford Beach Water

Parameter	---------- Component ----------				Communalities
	1	2	3	4	
PO_4^{3-}	**0.856**	-0.173	0.172	0.037	0.952
DO	**0.831**	0.042	-0.194	-0.012	0.817
Temp	**-0.824**	-0.141	-0.078	0.090	0.706
pH	-0.480	-0.175	0.170	0.408	0.649
E. coli	0.059	**0.983**	-0.048	0.089	0.952
T.Col	0.049	**0.982**	-0.039	0.092	0.952
NO_3^-	0.325	-0.475	-0.353	0.133	0.545
BOD	0.025	0.037	**0.854**	-0.164	0.704
SO_4^{2-}	0.085	-0.049	**0.743**	0.170	0.588
EC	0.244	0.052	-0.457	-0.411	0.634
TDS	0.012	-0.095	0.133	**-0.961**	0.902
Salinity	0.014	-0.067	-0.093	**-0.841**	0.752
Eigenvalue	4.059	2.229	1.422	1.115	
% of variance explained	33.826	18.575	11.852	10.085	
% of cumulative	33.826	52.401	64.253	74.339	

Extraction Method: Principal Component Analysis. Rotation Method: Oblimin with Kaiser Normalization. Rotation converged in 10 iterations.

Principal Component Analysis of Gbegbeyise Beach Water

Gbegbeyise Beach had 5 components extracted explaining 81.5% of the variance in the dataset (Table 4.25). Component 1 which explained 26% variance, had heavy loadings of EC, TDS and decreasing phosphate. Component 2 which explained the 20% variance, had heavy loadings of total coliform and *E. coli* counts of the variance. Component 3 which explained 13.3% of the variance had heavy loadings of pH with decreasing sulphate concentration. PCA 4 which explained 11.6% of the variance had heavy loadings DO with increasing temperature. PCA 5 which explained 10.1% of the variance had heavy loadings of DO and salinity.

Table 4.25 Principal Component Analysis of Gbegbeyise Beach Water

Parameter	---------- Component ----------					Communalities
	1	2	3	4	5	
EC	**0.984**	-0.075	0.073	-0.042	0.038	0.964
TDS	**0.975**	-0.094	0.177	-0.055	-0.108	0.948
PO_4^{3-}	**-0.669**	-0.128	0.385	-0.024	0.151	0.666
E. coli	-0.007	**0.985**	-0.059	0.020	0.068	0.972
T. Col	-0.007	**0.985**	-0.052	0.018	0.077	0.972
pH	0.009	-0.163	**0.853**	-0.082	0.142	0.757
SO_4^{2-}	-0.430	-0.210	**-0.577**	-0.228	0.008	0.598
NO_3^-	0.184	-0.283	-0.361	0.219	0.234	0.423
Temp	0.210	-0.057	0.038	**-0.939**	0.239	0.895
DO	0.101	-0.027	0.066	**0.866**	0.270	0.902
BOD	-0.254	0.136	0.167	-0.027	**0.887**	0.865
Salinity	0.426	0.022	-0.497	0.046	**0.525**	0.821
Eigenvalue	3.122	2.397	1.656	1.393	1.216	
% of variance explained	26.017	19.974	13.798	11.61	10.133	
% of cumulative	26.017	45.991	59.789	71.399	81.532	

Extraction Method: Principal Component Analysis. Rotation Method: Oblimin with Kaiser Normalization. Rotation converged in 11 iterations.

Principal Component Analysis of Gbegbeyise Estuary Water

The PCA analysis of the dataset for Gbegbeyise Estuary had 4 components with Eigenvalues greater than 1 extracted (Table 4.26). These components cumulatively explained 89% of the variance in the entire data set. With heavy loadings on EC, TDS, and salinity with decreasing temperature, component 1 explained up to 38.7% of the variance. With heavy loadings on nitrate concentration, total coliform and E. coli counts component 2 explained 27.3% of the variance. With heavy loadings on BOD and decreasing DO, component 3 explained 13.3% of the variance. The fourth component which explained 9.7% of the variance, had heavy loadings on phosphate with decreasing temperature.

Table 4.26 Principal Component Analysis of Gbegbeyise Estuary Water

Parameter	---------- Component ----------				Communalities
	1	2	3	4	
TDS	1.010	-0.157	0.251	0.065	0.952
EC	**0.986**	-0.155	0.063	0.018	0.963
pH	**0.803**	0.350	-0.096	-0.294	0.916
Salinity	**0.783**	-0.090	-0.399	-0.162	0.978
Temp	**-0.580**	-0.036	0.385	**-0.555**	0.977
NO_3^-	-0.062	**0.940**	-0.114	-0.084	0.899
T.Col	-0.091	**0.876**	0.237	-0.049	0.898
E. coli	-0.132	**0.874**	0.072	-0.057	0.819
SO_4^{2-}	-0.303	-0.492	0.429	-0.114	0.569
DO	-0.089	-0.043	**-0.931**	0.136	0.885
BOD	0.025	**0.580**	**0.683**	0.177	0.847
PO_4^{3-}	-0.136	-0.073	0.006	**0.969**	0.978
Eigenvalue	4.647	3.271	1.597	1.163	
% of variance explained	38.728	27.261	13.311	9.688	
% of cumulative	38.728	65.988	79.299	88.988	

Extraction Method: Principal Component Analysis. Rotation Method: Oblimin with Kaiser Normalization. Rotation converged in 12 iterations.

4.6 Documentation of the key findings from the focus group discussions (social survey)

4.6.1 Survey Summary

A social survey in the form of a focus group discussion was conducted in all the study communities to obtain information to support the quantitative data obtained to explore the possibility of coastal aquatic ecosystem components serving as diarrhoea transmission pathways.

The key thematic areas discussed were knowledge of diarrhoea, knowledge, and perceptions of diarrhoea transmission pathways within coastal aquatic ecosystems, sanitary practices and activities that may contribute to the formation of these pathways and, exposure to possibly contaminated coastal aquatic ecosystem components. The transcribed documentation of the discussions is presented in Table 4.27 below.

A total of hundred and sixty 160 individuals were interviewed for the survey. It was conducted in four (4) groups of eight (8) individuals each per community studied. The groups comprised female groups below the age of forty, female groups above the age of forty, male groups below the age of forty, and male groups above the age of forty.

Table 4.27 Focus group discussion report

Coastal Aquatic Ecosystems as Diarrhoea Transmission Pathways; A Focus Group Discussion Report		
Number of Participants: 160; **Communities:** Anyanui, Anyako, Atiteti, Mumford, Gbegbeyise		
Focus Group Composition: Group 1 - Old females of 40 years above (8 individuals) Group 2 - Old Males of 40 years above (8 individuals) Group 3 - Young Females of 18 to 39 years (8 individuals) Group 4 - Young Males of 18 to 39 years (8 individuals		
Major Occupations: Farming, fishing, fish mongering, welding, carpentry, teaching, hairdressing, catering		
Discussions on the thematic areas of the questions		
	Focus groups	**Remarks**
Knowledge of diarrhoea and what causes it	**Old Females** "We know what diarrhoea is" "Some causes are uncovered faeces, flies that lie on food, and not washing hands after using the toilet" "Dirty surroundings" "Dirty water and food" **Old Males** "We know" "I am not very sure" "Dirty environment and flies" "We know it, it is called 'dome'" . **Young females** "We know what causes diarrhoea" "We are not sure"	In every group at least one person knew what diarrhoea is and through discussions the others became aware. Contaminated food, flies, fomites, faecal matter, and poor garbage disposal which contribute to coastal pollution were listed. They however did attribute any to interation with coastal aquatic ecosystems.

	"Diarrhoea is common in our community but mostly it's the children who get it" **Young Males** "We have not heard of it" "Diarrhoea is normal in Anyako here, I get it often" "We know" "I think it is when you eat dirty food or peppery food"	
How often diarrhoea is contracted by participants	**Old females** "We barely have diarrhoea" **Old Males** "I barely get it" "I have it almost every week" "I have it one in a few days" "I have it mostly when we are at sea" **Young females** "Not very often" "Once in a few days" "Maybe monthly" **Young Males** "Not very often" "Once in a few days" "Most times when we are at sea"	Occurrences ranged from weekly and monthly to occasionally. It was not very common among older groups, especially women. Most older and some younger women attributed the occurrence to little children and fishermen of all ages. They also did not perceive diarrhoea as life-threatening.
Interaction with aquatic ecosystem components	**Old females** "We do not go swimming, but we sometimes relax at the beach" "We wash our fish in it" "We use the sand as skin scrub to relax and for infections" "We sometimes use it to scrub our pots at home"	All groups engage frequently in swimming except for the older women due to health and physical strength factors.

	Old Males “I used to go swimming but now I am too old” “I am a fisherman I love to swim” “I like to swim, it is relaxing” “We don’t swim too often because the mangrove swamp is getting salty and we are not used to it” **“**We sometimes take the salt water to wash our stomachs” “We use the salt water to mix with our cooking water” **Young females** “I barely swim” “I swim often” “I like to play in the water” **Young Males** “we swim a lot, we live near water” “We use the sediment for chicken pox” “I can not swim in this dirty water around”, said a teacher.	
Hygiene practices after interacting with aquatic ecosystem components	**Old females** “We often wash our hands and bath after handling fish” “We bath after contact with the sediment” **Old Males** “We bath after swimming” “We bath when we are back from fishing” “We bath after using sediment to scrub or lying in it” **Young females** "We always bath if we come back” “We wash our hands after doing dish work”	It was common among all groups to wash up or have a bath after long exposure to aquatic ecosystem components

	Young Males "We bath after swimming" "We bath when we are back from fishing" "We bath after using sediment to scrub or lying in it"	
Engagement in open defecation and reasons	**Old females** "We do not practice it" "We do it because it is airy and more relaxing" "I do it because the public toilets are not good" "It is the men and young boys who do it often, especially at dawn when they set off for fishing" "We have a toilet at home" "It is the people who come from inside town that do it even behind our windows" **Old Males** "I use the public toilet" "We around the mangrove do not do it" "I have a personal toilet at home" "We do it at sea" "I do it and bury it under the sand" **Young females** "I do not do it" "I do it often" "I use the public toilet" "I use the toilet at home" **Young Males** "We do it and bury it" "I use a public toilet" "I do it in the bush around"	Open defecation was admitted to be a common practice especially where there were poor toilet facilities. Some participants had personal toilet facilities in their homes and others had access to functional public toilets. Conversely, some others preferred open defecation for comfort and to avoid dealing with the challenges of toilet facility maintenance.

Managing household garbage	**Old females** "We take it to a central bin" "We burn it" "We dig and bury it" "We give it to informal waste collectors" "We throw it into the sea" **Old Males** "I burn it "It's the women who handle the garbage" "We have no sea defence so we use that as sea defence" **Young females** "We burn it" "We throw in in the sea" "We take it to the central garbage area" **Young Males** "I take it to the central garbage pile" "We take it to the pile but a lot of times it goes into the sea"	They admitted they needed better care for their waste, and proper management of public toilet facilities.
Perception of coastal aquatic ecosystem components as diarrhoea transmission pathways	**Old females** "It is not possible" "Only if you swim close to faeces" **Old Males** "It is not possible" "I have never heard of it" "The water takes all dirt away" "We even cook with seawater" "The sea water can be a laxative so it can not give diarrhoea" "Only those who do not live around could come and experience this all of a sudden"	Coastal waters are perceived as self-cleansing, therapeutic, and destructive to germs. The common belief was diarrhoeal illnesses could occur only if you touched garbage or faecal matter and handled food or household items or poor sanitary practices after defecating.

	Young females “It is not possible” **Young Males** “The water takes all dirt away” “We even cook sea water when we go fishing” “The public toilets are not good”	

Overall, it was observed that the residents understood what diarrhoea is. The knowledge of what causes diarrhoea was also clear to some and unclear to a few others. The residents also had a concurrent understanding of how their contracting diarrhoea was as a function of their sanitary practices before, during and after eating as well as how clear their surroundings were. In all communities, it was also observed that the females were mostly committed to practising good hygiene because it translated to their outlook. Most of the culprits of open defecation around the coastal waters in the communities were males and for the disposal of household waste around the coastal waters, females. The residents in all communities had a common perception that the coastal aquatic waters around them could not cause or be a pathway for diarrhoea transmission. Even though they admitted that being close to faecal matter and garbage may lead to diarrhoea and other diseases, they had a counter opinion that the waters move and can take away dirt. They also believed that the salinity of the waters would remedy any form of illness.

One menace at Atiteti and Gbegbeyise that made residents pay less attention to the occurrence of diarrhoea is the rise in sea level and the need for a sea defence.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Microbial contamination in water samples

5.1.1 Total coliform count and *E. coli* count

The average total coliform counts for all communities exceeded the US EPA (2012) recreational water quality criteria of 2300 CFU/100mL or 3.36 (log variant) limit (Figure 4.11). This was observed mostly in the rainy season. According to studies by the U.S. Public Health Service, when total coliform density was around 2,300 per 100mL in recreational waters, there was a discernible negative impact on health and the spread of diseases like diarrhoea. High levels of total coliforms suggest that the water may be contaminated with other harmful pathogens such as bacteria, viruses, and parasites that cause diarrhoeal diseases. These pathogens can infect individuals who come into contact with or consume contaminated water, leading to gastrointestinal illnesses. The results were above the minimum and exceeded the maximum values recorded by Akita *et al*., (2021) in their study of coastal beaches in the same sampling areas. Anyanui had the lowest total coliform count overall compared to all other sampling sites (Figure 4.11). Similar but slightly higher counts were observed by Akita *et al*., (2021) in the same sampling area. These increased records of total coliform counts in this study are indicative of increased pollution -within all other communities except Anyanui.

Overall Gbegbeyise Beach had the highest record for the total coliform count, Gbegbeyise Beach had the next highest, Mumford was the third, Anyako was fourth, Atiteti in fifth place and Anyanui in sixth place with the lowest count in this study

The monthly average *Escherichia coli* count for the water samples had higher records (Figure 4.12) than counts recorded by Akita *et al*., (2021) within the same sampling areas. Both studies however had the lowest *E. coli* count in Anyanui. A similar observation was made for the total coliform count. Gbegbeyise Estuary and Gbegbeyise Beach had the highest and second-highest counts respectively.

Sewage discharges, urban runoff, agricultural runoff, failing septic systems, animal wastes, recreational activities, industrial discharges, and poor waste management form pathways through which coliforms and other pathogens get into coastal waters (ICMSF 2005). Open defecation was a common practice that was observed and openly admitted by interviewed residents in all communities except Anyanui and this was evident in the coliform enumerated (Figure 4.12). This practice is known to be a key contributor to human-induced environmental disturbances, particularly in rural and impoverished regions of Sub-Saharan Africa. It increases nutrient levels and microbial pollutants that are of environmental and public health concern (Kilinc & Besler, 2014; Conserve Energy Future, 2022). These practices were observed more in the Gbegbeyise which had the highest counts. The presence of an estuary which is a conduit for solid and liquid waste from a range of communities is also a contributing factor. The study communities also engaged in agricultural activities (plants and or livestock), had challenges of poorly disposed of household and municipal waste as well as dilapidated public toilets.

For all the communities which had *E. coli*, the highest or only records were detected mostly in the rainy season in the rainy season. Where and when *E. coli* were present and enumerated, counts exceeded the ≤ 200 CFU/100ml (or Log variant 2.30) 2012 Guidelines for Canadian Recreational Water Quality. The occurrence of counts beyond

this level implies that the water bodies have crossed the "No observed adverse effect levels" (NOAELs) and have statistically been proven to result in gastrointestinal illnesses in humans. Aside certain strains of *E. coli* being enteropathogenic, it serves as an indicator organism. Hence its presence also implies that other pathogenic bacteria and or microorganisms are present, faecal contamination is occurring and there is a potential presence of sewage pollution within those water bodies (Guillaud *et al*., 1997; Medema *et al*., 2003; Stewart *et al*., 2008; EPA, 2012; Health Canada, 2012; Korajkic *et al*., 2018). The presence of E. coli counts above the USEPA limits in almost all sampling months in Gbegbeyise Beach and Estuary indicates their water bodies are of very poor quality and harbour diarrhoeagenic bacteria that can influence diarrhoea contraction in those communities.

5.1.2 Microbial load and contamination parameters in biota samples

Overall, the biota samples from Anyako fishing lagoon had the highest records for the total coliform count and *E. coli* count (Table 4.1). For all biota samples where total coliform and *E. coli* counts were recorded the highest counts were recorded in the rainy season except for Anyanui which had the highest record in the dry season. Coliforms and pathogens are found in biota when they are present in the water bodies. Globally, fish and shellfish constitute significant sources of animal protein. Foodborne illnesses brought on by pathogenic bacteria can be spread through seafood items (CSPI, 2007). Cold-blooded creatures, fish and shellfish can be captured or harvested in a variety of environmental settings. The state of the aquatic habitat in which the fish are captured is often represented by the quality of the biota caught (ICMSF 2005). According to the ICMSF (2011), raw fish testing does not ensure safety because of the forms a which it is consumed and more focus for testing should be on its post-harvest and processing

procedures. For this reason, the counts for the fish were not considered. However, the counts enumerated per gram exceeded the 2300 CFU/100ml and 200 CFU/100ml US EPA water limits. for total coliform and *E. coli* counts respectively. This supports the notion that the microbiota of the fish is a reflection of the aquatic habitats they are found in. It also implies that much attention should be given to the processing phase of these fish before consumption.

The ***Crassostrea gasar*** mangrove oyster was the biota of choice for the Anyanui mangrove swamp. The key safety indicator for bivalve molluscs is *Escherichia coli*. Only two months in the sampling period had records of *E. coli* count. One in the dry season and the other in the wet season. The dry season's counts were higher than the wet season's. Both counts exceeded the 3-5 CFU/g ICMSF (2011) limits. These limits represent marginal (≥3 CFU/g) to unacceptable quality (>5 CFU/g). The count for total coliforms which can also be classified as an indicator of indirect hazard exceeded the (5,100 CFU/g) ICMSF limit. Molluscs can also cause foodborne illnesses as they are bottom feeders and accumulate pathogens and other microorganisms for a long time. Processing is not too heat-intensive and may be limited due to hardy shells, resulting in pathogens persisting. The European Union have in previous times even classified the water bodies they are found in based on the concentration of pathogens found in them. These results imply that the oysters sampled from the Anyanui mangrove possess faecal indicator bacteria which signals the presence of other diarrhoeagenic and other pathogenic microorganisms in the water bodies and fauna at levels that could result in human infections if ingested.

5.1.3 Microbial load and contamination parameters in sediment samples

All communities that had *E. coli* counts were within the 1-100 CFU/100g WHO (2021) range of high infectivity. Gbegbeyise Beach and Anyako Fishing Lagoon exceeded these limits in more months than all other communities (Table 4.2). Coastal sediments which are made up of sand, mud or pebble particles are often used recreationally and, in some instances, sediment is used more than time is spent in the water (WHO, 2021). The coastal communities except those around Anyako and Anyanni because of the clayey nature of the sediments, made use of their beach sediment for recreational purposes like relaxation, therapeutic body scrubs, pot scrubbing and even minor domestic building projects. Bacteria are an important and commonly found component of coastal sand and sediment. Some of these bacteria are pathogenic. Making these sands and sediments pools or pathways of infection and mediums through which water sources are contaminated. Even though coastal waters carry along these pathogens from ashore into the sediments through tidal wave action and the churning of sediments enables the reintroduction into the waters (Whitman *et al*., 2014; Solo-Gabriele *et al*., 2016; Weiskerger *et al*., 2019).

Sediments with higher quality have proven to connote the high quality of the surrounding water (WHO, 2021) and vice versa. This was observed in this study where sediments with higher total and *E. coli* counts had their surrounding waters reflecting similar records.

5.2 Distribution of identified bacterial isolates from the biota, sediment and water samples per community

In the sampling areas over the entire sampling period, the sediment samples had the highest abundance of indicator and target pathogens isolated, with the biota samples being the next most endowed component. In all communities, the water samples had the

least abundance of target indicator bacteria and diarrhoeagenic bacteria (Figure 4.13 to 4.15). It has been proposed that sediments act as faecal contamination sinks as they can host as many pathogens that can bind to the particles (Halliday & Gast, 2011). sediments have proven to be great reservoirs of faecal indicator bacteria and other enteropathogens especially those that arise from storm or rain runoffs from adjacent lands and elevated lands, and this can in turn affect receiving waters during rainy seasons (Brownell *et al*. 2007). Bai & Lung (2005), Hall-Stoodley *et al*. (2005), Haack *et al*. (2015), and Liao *et al*. (2015) in their studies observed that the survival and persistence of some enteropathogens and faecal indicator bacteria were due to their increased abilities to attach to sediment resulting in sediments having a higher bacterial load. Sediment particles especially those of a clayey nature have a larger surface area than those of a coarser nature which increases the chances of bacterial attachment and accounts for high bacteria counts and pathogens. This occurrence was observed in Anyanui and Anyako which had soils of clayey texture and relatively high pathogen load compared to the other areas sampled. Yamahara *et al*. (2012) in their research observed that sediment had higher counts of faecal indicator bacteria (FIB) compared to water making them capable of infection spread. This occurrence in extension affects the water quality (Fewtrell & Kay, 2015).

In research conducted on two beaches by the National Epidemiological and Environmental Assessment of Recreational (NEEAR) Water study (by the US EPA and Centre for Disease Control), qualitative data gathered from bathers revealed all bathers admitted to churning and interacting with the sediment. At the end of the analysis, it was discovered that there was a high association between high counts of faecal indicator organisms, interaction with beach sand in the process and the occurrence of

gastrointestinal illnesses (Heaney *et al*., 2012). The presence of higher loads of pathogens found in the sediments in this study can therefore pose a threat and possible pathway for contact with and the spread of diarrhoeagenic bacteria. Continuous exposure could also result in the contraction of diarrhoea Higher loads of pathogens were observed in the rainy season. High tides and increased rainfall have been known to affect the level of pathogens and indicator bacteria concentration. This is because of urban storm runoffs and the submerging of the intertidal zone during high tides which may lead to the resuspension of sediment and sand increasing the transfer of pathogens into the water (Abdelzaher *et al*., 2010; Korajkic *et al*., 2011).

5.3 Water quality status based on the European Union's 95th-percentile rating

This was determined by subjecting the log10 normal probability density of the *Escherichia coli* present in the water according to the European Union management of bathing water quality and reporting directive (76/160/EEC) 95-percentile evaluation {Status Value = antilog ($\mu + 1.65\sigma$)} (European Union, 2006). Following this analysis, the ranking of the water quality from the healthiest to the least was; Anyanui mangrove swamp water, Anyako, Atiteti and Mumford Beach, Gbegebyise Beach and lastly Gbegbeyise Estuary. The records for the poor health rating in the different communities were observed mostly in the rainy season (Figure 4.16 to 4.21). High counts of E. coli (faecal indicator bacteria) influenced the poor ratings of the water High tides and increased rainfall have been known to affect the level of pathogens and indicator bacteria concentration. This is because of urban storm runoffs and the submerging of the intertidal zone during high tides which may lead to the resuspension of sediment and sand increasing the transfer of pathogens into the water (Abdelzaher *et al*., 2010; Korajkic *et al*., 2011). Water samples from the communities that had poor health ratings

had their sediment and biota samples also laden with high concentrations of other faecal indicators such as *Enterococcus faecalis* and target pathogens such as Vibrio species, salmonella, and *Escherichia coli*. Anyanui had more concentration of the pathogens and indicator bacteria in its sediment and biota samples this may be because of minimal resuspension. The clayey nature of the sediments requires disturbance for particles that have bacteria attached to get mixed with the water. A review of four prospective cohort studies conducted within the United States revealed the occurrence of diarrhoea occurred more among swimmers as compared to non-swimmers. In all studies, correlations of faecal indicator bacteria (specifically *E. coli* and Enterococcus) with risks and odds of disease occurrence were high following analysis of data collected (Marion *et al*., 2010; Colford Jr. *et al*., 2012; Dorevitich *et al*., 2012a; Dorevitich *et al*., 2012b). These also concur with theories that try to show that indeed there are strong correlations between the presence of indicator bacteria and other pathogens (US EPA, 2012; WHO, 2021); and also between loads of pathogens found in the sediment, water and biota of coastal and recreational waters (ICMSF, 2005; WHO, 2021). It also implies that interactions with these components present the risk of getting infected by pathogens that have established pathways of spread via these components.

5.4 Interactions between physicochemical parameters and the microbial contamination indicators

Pearson's correlation analysis revealed the following significant relationships between the physicochemical parameters and bacterial indicators measured ($p < 0.05$/ 95% CI).

5.4.1 Atiteti Beach

Positive correlations in Atiteti included total coliform and sulphate, (Table 4.3 to 4.5). A key source of sulphate in coastal waters among many anthropogenic and natural activities includes household waste and industrial and wastewater discharge. (Moreno-

Casas *et al*., 2009). Sulphate and *E. coli* levels had positive correlations which can be explained by the reasons why sulphate and total coliforms are correlated (USEPA, 2012). *E. coli* is a type of coliform which is a faecal coliform, a subgroup or constituent of the total coliform bacteria group (Bettelheim, 2003) and this increases the likelihood of *E. coli* having a similar correlation. Hence a positive correlation is in order. Positive correlations also indicate coliforms can thrive in such conditions Poor waste collection and disposal is a challenge in this community and during seasons of high tides, waste is always able to make its way into the coastal water.

Nitrate, BOD and total coliform had positive intercorrelations. BOD is used as a measure of the level of pollution, especially with wastewater and other forms of waste that elevate organic matter in coastal waters (Vijayakumar *et al*., 2014). Nitrate equally serves the same purpose and indicates faecal, sewage and other industrial discharges which also contribute to organic matter impacting oxygen levels due to the increased presence and activities of microorganisms, total coliforms being a group of those microorganisms (US EPA, 2012). Open defecation is commonly practiced along the coast which could also impact nitrate levels alongside household waste making its way into the water.

5.4.2 Mumford Beach

TDS significantly correlated with the total coliform count. The records for Mumford had the highest TDS record compared to all other communities' beaches. The considerable increase in levels of total dissolved solids in water emanates from natural sources, wastewater discharges, industrial effluent, and urban and agricultural runoff (Akita *et al*., 2021; Avornyo, 2017). All sampling points at Mumford were low-lying and very close to coastal residencies which were slightly elevated. Open defecation and

open refuse dumping were common practices observed at the sampling points. All these contribute to an increase in TDS levels as well as coliform concentrations (Akita *et al*., 2021; Avornyo, 2017).

5.4.3 Gbegbeyise Beach

During the dry season, *E. coli* positively correlated with sulphate levels. Gbegbeyise Beach had the highest records of sulphate (Figure 4.10). As espoused in 5.4.1 The introduction of *E. coli* into waterways may also arise from similar sources as sulphur including open dumping of refuse into surrounding water bodies. This was a very common practice in Gbegbeyise. Studies have also shown that the presence of sulphate in significant concentrations also signals high microbial activities (Moreno-Casas *et al.*, 2009) in marine water bodies. The same relationship was observed at Atiteti Beach. This relationship in the dry season may be influenced by the absence of high tides, reducing the continuous mixing of water from the coastline and more flow from the adjacent estuary. The total coliform counts negatively correlated with salinity and electrical conductivity (EC) which had significant correlations. The detrimental impact of the wide range of biotic and abiotic elements in marine environments influences the cells of *E. coli* introduced into them. The impact of temperature, salinity, and especially sun radiation is most apparent among abiotic variables (Carlucci & Pramer, 1960; Šolić and Krstulović, 1992). conductivity and salinity are highly correlated and they both are increased by the concentration of dissolved ions (Avornyo, 2017) and can equally affect *E. coli* levels. Lowered salinity can reduce osmotic pressure on *E. coli* cells and promote growth whereas elevated levels of salinity can inhibit its growth (Li *et al*., 2021). *E. coli* however eventually adapts to these conditions.

5.4.4 Gbegebyise Estuary

In the dry season, *E. coli* positively correlated with sulphate. This relationship especially within highly polluted estuaries is expected due to the impact of high anthropogenic activities as espoused for Atiteti (5.4.1). Gbegbeyise estuary stems from Ablekuma township flowing into a confluence with the Chorkor community and flowing at the estuary at Gbegbeyise. In the rainy season, total coliform positively correlated with biological oxygen demand (BOD) and Nitrate and can be similarly accounted for by anthropogenic activities as in Atiteti (5.5.1). Total coliform negatively correlated with dissolved oxygen (DO). Decreasing DO signals excessive microbial activity and harms aquatic life (Stumn & Morgan, 1981; DFID, 1999; WHO, 2003). This can also increase BOD levels. Gbegbeyise estuary had the highest BOD records (Figure 4.7). The estuary collects faecal, domestic, and municipal wastes of all sorts which drain into the sea adjacent to the Gbegbeyise estuary. Due to the negative impact of low DO levels, there were no biota seen or harvested as a representative for that water body even when sand bars were formed and there was no outflow or influx from the sea. E.coli, total coliform and nitrate were positively intercorrelated especially in the rainy season.

5.4.5 Anyanui Mangrove Swamp

In the dry season, total coliform positively correlated with sulphate and phosphate. The increased concentration of phosphate ions is thought to be caused by runoff from nearby farms, municipal and industrial waste, urban storm drainages and faecal matter from animals, (Lee *et al.*, 1977; Pucket, 1995). There were a lot of farming activities around the mangrove swamp which may have contributed to increased nutrient levels. Being a wetland there will also be a lot of accumulated nutrients and organic matter, especially within its sediment and this can be stirred into the water when churned. Increased

nutrient and organic matter in water also signal the presence of microorganisms like coliforms (Moreno-Casas *et al.*, 2009).

5.4.6 Anyako Fishing Lagoon

There were no significant correlations observed between the physicochemical parameters and the microbial indicators enumerated.

5.5 Principal Component Analysis

5.5.1 Principal Component Analysis of Atiteti Beach Water

In Atiteti the three principal components extracted accounted for 63.9% of the total variance observed (Table 4.21). Component 1 correlated strongly with increasing salinity, conductivity and total dissolved solids. These three parameters were highly correlated statistically and are expected to increase simultaneously in saline conditions where an increase in one variable will also influence an increase in all others. Increasing TDS also results from anthropogenic activities that influence the introduction of waste and pollutants into seas and around beaches. Component 2 correlated strongly with BOD, nitrate and total coliform and increased simultaneously. Open defecation, nearby plantations and farms, poor disposal of refuse at an open dumpsite which is usually disturbed during rainfall and high tidal waves are conditions observed within Atiteti. These are factors that contribute to nitrate levels and impact high microbial activity thereby causing an increase in BOD. Component 3 correlated strongly with *E. coli*, phosphate, nitrate and decreasing DO. The anthropogenic and climatic factors affecting Component 2 suit the loadings in Component 3. High microbial activity and organic matter decrease oxygen levels which implies that DO influences increased levels of the other parameters.

5.5.2 Principal Component Analysis of Anyanui Mangrove Swamp Water

Three components were extracted for this sampling and best explained 79.8% of the variance (Table 4.22). Component 1 was more influenced by BOD, nitrate and decreasing DO. Runoffs from livestock farming, faecal waste, and farms which were observed around the water bodies in Anyanui are likely to cause high loadings of the parameters in component 1. These are factors that contribute to nitrate levels and impact high microbial activity. These also result in an increase in BOD due to the high organic contents and microbial activities which reduce oxygen levels. The presence of faecal matter in the water bodies and the corresponding increase in BOD levels in these water bodies makes them good surrogates for faecal and diarrhoea bacteria (EPA, 2012; Guillaud *et al*., 1997; Health Canada, 2012; Korajkic *et al*., 2018; Medema *et al*., 2003; Lleo *et al*., 2005 Garcia-Migura *et al*., 2007; Leavis *et al*., 2007; Stewart *et al*., 2008; Palmer *et al*., 2010).

5.5.3 Principal Component Analysis of Anyako Lagoon Water

Four components accounting for a total of 76.8% of the variance were extracted (Table 4.23). In Component 1 Strong correlations were observed with TDS and salinity conductivity, nitrate, temperature, and BOD with decreasing pH. The Anyako fishing lagoons had very high saline conditions due to the concentration of saline water within the formed lagoons. The interaction between the sea and the lagoons is quite important because the water is abundant in ions due to its dissolved salts. Poor sanitary conditions were observed with household wastes found close to the shores and the dumping of fish parts right into the water and at the shore during the fish cleaning. This can impact nitrate and TDS levels. Nitrates are acidic in nature and increasing nitrate will influence a decrease in pH. In Component 2 Strong correlations were observed with total coliform

and increasing BOD. High coliform and BOD are impacted by waste and other anthropogenic activities and high recreational and fish harvesting and cleaning activities around the water. In Component 3 Strong correlations were observed with decreasing DO and increasing phosphate. In Component 4, a Strong correlation was observed with *E. coli* count. The occurrence in components 3 and 4 results from the high anthropogenic activities and the presence of *E. coli* is an indication of faecal contamination from both animal and human input (Guillaud *et al*., 1997; Medema *et al*., 2003; Lleo *et al*., 2005 Garcia-Migura *et al*., 2007; Leavis *et al*., 2007; Stewart *et al*., 2008; Palmer *et al*., 2010; EPA, 2012; Health Canada, 2012; Korajkic *et al*., 2018).

5.5.4 Principal Component Analysis of Mumford Beach Water

In Mumford, four components were extracted which explained 74.3% of the variance (Table 4.24). Principal component 1 had high loadings of phosphate and dissolved oxygen with decreasing temperature. Component 2 had high loadings of total coliform and *E. coli*. High anthropogenic activities, poor waste disposal, fish harvesting and cleaning, as well as open defecation, influence the loadings in this component. Component 3 had high loadings of BOD and sulphate. Sulphate and BOD levels are increased due to the presence of waste matter that can impact nutrients and increase microbial activities.

5.5.5 Principal component analysis of Gbegbeyise Beach water

Gbegbeyise Beach had 5 components extracted explaining 81.5% of the variance (Table 4.25). Principal component 1 had strong correlations with EC, TDS and decreasing phosphate. Principal component 2 had strong correlations with total coliform and E. coli counts of the variance. Being the second most microbially contaminated site, total coliform, and *E. coli* contributing the second highest to the variations in the data was

expected. Gbegbeyise Beach and Estuary were always visibly heavily polluted with household, faecal and municipal waste.

5.5.6 Principal Component Analysis of Gbegbeyise Estuary

The PCA analysis of the dataset for Gbegbeyise Estuary had 4 components extracted which cumulatively explained 89% of the variance (Table 4.26). EC, TDS and salinity had high loadings in component 1. Nitrate, total coliform, and E. coli had high loadings in component 2. BOD and decreasing DO had high loadings in component 3. Phosphate and decreasing temperature had high loadings in component 4. The estuary which collects waste and runoffs of all forms, the presence of anthropogenic activities, and open defecation in and around the estuary all affect the loadings observed in components 2, 3 and 4.

Overall, the principal component analysis revealed that the most contributing parameters to the variance in the data set, corresponding with an increase in the levels of coliforms were: increasing conductivity, total dissolved solids, biological oxygen demand, nitrate, phosphate and sulphate alongside decreasing dissolved oxygen. Significant relationships have been observed between high counts of microbial indicators and parameters such as nitrate, conductivity, total dissolved solids, and dissolved oxygen concentrations in recent studies (Akita *et al*., 2020). These parameters are typically indicators of pollution within aquatic ecosystems, usually brought on by anthropogenic activities and exacerbated by climatic factors. The study communities are communities that have been impacted by climate change and secondary impacts which affects the livelihood and quality of life. The results of the analysis also corroborate with the literature reviewed and adapted to develop the conceptual framework for this study (Figure 2.1). Indeed, climatic and anthropogenic factors

impact coastal ecosystems and also create a conducive environment for diarrhoeagenic bacteria to thrive. This also makes coastal marine ecosystems pathways for them to be spread.

5.6 Perception of participants on sanitary practices and diarrhoea transmission pathways

The social survey revealed that the participants knew what diarrhoea is. They were able to articulate what they knew could cause diarrhoea. The causes listed were not linked directly to the components of the coastal aquatic ecosystem. Reconnaissance visits to nearby over-the-counter chemical shops and municipal health directorates revealed there were indeed reports of diarrhoea cases. There were also events of meagre treatments where patients did not buy the recommended amount or did not complete the medication courses as they did not view diarrhoea as life-threatening. This can also be deduced from their responses during the focus group discussions (Table 4.27). When questions were posed to the participants about their perceptions of diarrhoea contraction as a function of the state of marine ecosystems, they expressed disbelief. They only understood it as a function of maintaining good sanitary practices within their homes and not necessarily around the coastal waters. This is because they believed the water bodies were not stagnant and could get rid of any form of pollutant input into them. This is believed to have influenced their indiscriminate dumping of refuse, open defecation, and poor management of household waste among many other practices that may pollute the aquatic ecosystems (Table 4.27). The use of aquatic ecosystems as a means of garbage disposal and disposal of other forms of potentially harmful waste (e.g. organic waste, fertilizers, chemicals etc. according to the Science Advice for Policy by European Academies (SAPEA) is partly because of the false notion that the seas and the global

ocean could absorb and recycle all forms of toxins. This has consequently resulted in increased dangers to the environment and human health (SAPEA, 2019).

In light of the increasing use of aquatic ecosystems and an existing perception of their ability to rid pollution, Borja *et al.* (2020) identified some key areas they deduced from extensive studies were responsible and recommended keen attention and interventions, especially in developing countries. These challenges were equally identified within the study communities and can easily be linked to their perceptions of coastal marine pollution as well as the occurrence of diarrhoea through coastal marine pathways. They include:

1. Limited or relatively weak environmental awareness. Without adequate awareness of how marine ecosystems get polluted through anthropogenic activities, community residents may unknowingly expose themselves to diarrhoeagenic bacteria. An inadequate understanding of safe practices as avoiding interaction with contaminated components increases the risk of diarrhoeal illnesses stemming from these components.
2. Inadequate understanding of the threats coastal marine ecosystems face from pollution in the face of climate change and how the secondary impacts of these threats become detrimental to the well-being of humans and the ecosystem as a whole. When the health of a coastal marine ecosystem is threatened it compromises the quality of its resources. Community residents with a poor understanding of this are unable to contribute to managing menaces that arise which include the proliferation of diarrheagenic pathogens. This can also elevate the risks of contracting diarrhoea.

3. The right actors or leaders of the community and key stakeholders do not have the right education to help shape their outlook and behaviour towards coastal ecosystems. Without the right knowledge, they may not prioritize conservation efforts or sustainable practices leading to pollution and habitat destruction. This can result in the deterioration of water quality and an increased risk of diarrhoeal diseases as community members may not receive proper guidance on safe practices concerning contaminated water, sediment, and biota. This eventually perpetuates a cycle of environmental degradation and health risks in the coastal communities.

These areas were deemed key and improving on them was seen as achievable solutions to achieve better coastal ecosystems' health and by extension human health and sustainability. These key areas of concern are also recommended for improvement in the selected coastal communities for this study as well.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

This study was aimed at contributing to knowledge and providing evidence through mechanistic and holistic approaches about diarrhoea transmission pathways within coastal aquatic ecosystems of selected coastal communities. The selected coastal communities were within the Central and Eastern coasts of Ghana. They experience incidences of diarrhoeal diseases and were impacted by the effects of climate change and pollution from poor sanitary conditions which could in turn exacerbate the proliferation of diarrhoeagenic bacteria

The objectives of this study were to; identify and quantify water pollution proxy indicators, diarrhoeagenic bacteria and faecal indicator bacteria; determine their associations; assess the health status of the water bodies; and finally, understand the perceptions of the community residents about diarrhoea contraction via coastal aquatic components by engaging community residents in focus group discussions.

The total coliform and *Escherichia coli* (*E. coli*) counts for the surrounding coastal water bodies in each community were above the limits as determined by the USEPA 2012 recreational water quality guideline limits. Making them potential hubs for pathogens implicated with gastrointestinal diseases like diarrhoea. Anyanui mangrove swamp river however had no occurrence of *Escherichia coli*. All maximum values were observed in the rainy season. For the biota samples, the mangrove oyster at Anyanui exceeded the ICMSF unacceptable quality limit of 5 CFU/g with a range of 220 to 16000 CFU/g. No limits were applied to the fish samples as recommended by ICMSF

(2005, 2011) due to the heat processing they undergo before consumption. The maximum counts of total coliform and *E. coli* seen in the fish samples per gram exceeded the limits set for the water by the USEPA by far. This supports the notion that the microbiota of the fish reflects the quality of the water.

Diarrhoeagenic bacteria were isolated from the water, sediment, and biota in all the communities with sediment samples being the most laden. Salmonella, Vibrio species, *Escherichia coli*, and *Enterococcus faecalis* were the only target bacteria isolated. Increasing biological oxygen demand, phosphate, sulphate, nitrate and total dissolved solids with decreasing dissolved oxygen served as proxy indicators of pollution in the water samples. They also influenced and correlated with the presence of increasing counts of coliforms. These contributed the most to the variance in the data as well as enabling the identification of anthropogenic sources of pollution contributing to the formation of diarrhoea transmission pathways following a principal component analysis. All communities' water samples which had *E. coli* count were rated poor with scores ranging from 1512 to 49720000 way above the >500 mark for poor water quality according to the EU 95-Percentile rating. The poor ratings were observed more in the rainy season. The observation of increased indication of pollution during the rainy season indicated seasonal variations played a role in the presence of diarrhoeagenic bacteria and the spread of diarrhoea in that season. The mangrove swamp at Anyanui was the only aquatic ecosystem that was rated healthy throughout the sampling periods. However, its sediment and bivalve mussels were laden with some diarrhoea bacteria. This pronounced the benefits of wetlands in the filtering and purification of water systems. All others especially within the rainy season were impacted by high faecal coliform count.

From the focus group discussions, it was deduced that residents knew what diarrhoea was, had experienced it and the majority even knew what could cause it. Of all the causes listed none were related to the aquatic ecosystems. Residents were of the perception that the coastal waters washed away the faecal matter and household or municipal waste. Hence, their indiscriminate disposal, flood events or tidal waves washing gathered waste did not have any significant impact on the water bodies. They also strongly believed the salt content was not only therapeutic but also able to inhibit any possible disease-causing organism.

6.2 CONCLUSIONS

1. **Water Quality and Pathogens:** The coastal water bodies in the communities studied exhibited high levels of total coliform and *Escherichia coli (E. coli)* counts, exceeding the recreational water quality guideline limits. This occurrence was also observed for the aquatic fauna and sediments. The results serve as indications that these waters serve as potential hubs of pathogens associated with gastrointestinal diseases like diarrhoea.

2. **Seasonal Variation:** Maximum bacterial counts and pathogen loads were observed during the rainy season, suggesting a seasonal influence on water quality and pathogen presence.

3. **Microbiota Reflection:** The study found that fish samples reflected poor water quality, as their bacterial counts exceeded the limits set for water bodies. This suggests that the microbiota of fish can be indicative of the overall water quality.

4. **Presence of Diarrheagenic Bacteria:** Diarrheagenic bacteria like Salmonella, Vibrio species, *Escherichia coli*, and *Enterococcus faecalis* were isolated from water, sediment, and biota samples across all communities. Sediment samples had the highest pathogen presence, indicating their role as reservoirs.

5. **Pollution Indicators:** Indicators of pollution such as increasing biological oxygen demand, phosphate, sulphate, nitrate, and total dissolved solids (TDS), along with decreasing dissolved oxygen, correlated with higher coliform counts. They pointed to anthropogenic pollution sources that contributed to diarrhoea transmission pathways in the study communities.

6. **Water Quality Ratings:** The water samples from all communities containing *E. coli* were rated as poor quality according to the EU 95-percentile rating. This poor quality was indicative of poor health status that was more prevalent during the rainy season. This also suggests that there is a nexus between increased pollution, seasonal variations, poor coastal aquatic health status and the formation of pathways for the spread of indicator and diarrhoeagenic bacteria

7. **Wetland Benefits:** The Anyanui mangrove swamp demonstrated its ability to maintain healthier water quality throughout the sampling periods, showcasing the benefits of wetlands in filtering and purifying water systems.

8. **Local Perceptions:** Despite the evidence of contamination and pollution, the residents held the perception that coastal waters could wash away waste and that salt content had a protective effect against disease-causing organisms. This impacted how they did not pay much attention to the introduction of pollutants that could result in diarrhoea contraction into the surrounding ecosystems.

6.2 RECOMMENDATIONS

Based on the deductions from this research the following recommendations are made

1. **Further research**

   Further research to understand the specific sources of contamination and factors contributing to the persistence of diarrhoeagenic bacteria is highly recommended. This can inform targeted interventions for sustainable water quality improvement. Further prospective cohort studies can also be conducted to be able to understand the odds and extent to which community residents are at risk and can be affected by their interactions with polluted aquatic components. This study was limited to six months which was not sufficient to evaluate exposure risk. Technical and time limitations in this study permitted only the enumeration of indicator bacteria and identification of the pathogens. Enumeration of the microbial loads of the pathogens present can be considered for further studies. This study was also limited to only diarrhoea bacteria pathogens. A wide range of notorious microorganisms especially the Noro Virus, Rotavirus and *Giardia lamblia* parasite have been implicated with diarrhoea and can persist in coastal areas. These can also be considered for further studies.

2. **Water quality monitoring**

   Implementation of regular and rigorous monitoring of water quality in the coastal communities, focusing on bacterial indicators and pollution levels is highly recommended. This can help identify trends, assess the effectiveness of mitigation measures, and guide policy decisions. The government of Ghana through the Ministry of Environment, Science, Technology and Innovation

(MESTI) and the Environmental Protection Agency (EPA) alongside key public health and coastal management institutions (including non-governmental organisations) should aid in the development of water quality, food and sediment quality standards tailored to the conditions of our water bodies. Locally tailored criteria would facilitate strategies best suited to the local challenges.

3. **Seasonal management**

   Keen attention should be paid to the influence of seasonal variations on water quality and pathogen presence. This would help in implementing additional measures during rainy seasons to mitigate increased pollution and its impact on diarrhoea transmission and other water-borne diseases in coastal communities.

4. **Collaborative targeted public awareness and education**

   Targeted awareness campaigns to educate residents about the connection between water quality, pollution, and health should be developed. This would help to correct misconceptions and provide evidence-based information about the potential risks associated with contaminated water sources. Intensive and continuous education of coastal communities based on significant findings from studies like this should be carried out often. This can be done with the help of collaborative efforts from related research institutes, Non-Governmental Organisations, municipal health directorates and community leaders local authorities, and communities.

5. **Wetland conservation**

   Wetland conservation and its benefits in terms of water filtration and disease prevention should be promoted. The importance of wetlands, like the Anyanui

Mangrove in maintaining water quality, should be emphasized seeing the role it played in limiting the diarrhoeagenic bacteria to the sediment and biota.

6. **Waste disposal infrastructure**

   Waste disposal infrastructure and practices within the communities to reduce the influx of pollutants into coastal waters should be improved. This includes managing household and municipal waste and preventing indiscriminate waste disposal.

7. **Policy enforcement**

   Regulations related to water quality and pollution control should be strengthened as well as responsible practices among industries within urban areas, and individual anthropogenic activities that contribute to water pollution.

These recommendations fall not only on the shoulders of authorities and governing bodies but also on the communities that have a key role to play in engaging in sustainable sanitary practices. Pathogens may always exist in coastal aquatic ecosystems and certain natural and biophysical conditions may contribute to this. However, well-informed perceptions that help reduce man-made pollution and exposure to pollutants will go a long way in reducing the risk of diarrhoea contraction and augmenting external interventions.

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APPENDICES

Appendix 1 Interview Guide for Focus Group Discussion

Interviewer: Sylvia Salama Opoku

Introduction

The purpose of this interview is to obtain information that will be used to explore the possibility of coastal aquatic ecosystem components serving as diarrhoea transmission pathways and the risk involved for exposed community members.

This study is conducted in partial fulfilment of my MPhil. program in Sustainability Science at the University of Ghana. Your cooperation and willingness to answer these questions are important for the completion and success of my study. You are kindly required to answer all questions giving clear answers appropriate for the questions being answered. Please be rest assured that I will only use your information to further my research and any other study that will lead to the improvement of any deplorable conditions that may exist within your community as it relates to the occurrence of diarrhoea.

Key Areas: Knowledge of diarrhoea, knowledge and perceptions of diarrhoea transmission pathways within Coastal aquatic ecosystems, sanitary practices and activities that may contribute to the formation of these pathways and, exposure to possibly contaminated coastal aquatic ecosystem components.

A. Introduction and Demographics [Age groups, gender, occupation(s)]

B. Do you know what is and what it could be caused by?

C. Do you get diarrhoea and how often? (Seasonality/months)

D. Do you know of things you come in contact with that can lead to diarrhoeal infections?

E. Are there things you do that you think can lead to you contracting diarrhoea?

F. How often do you go swimming, and do you wash your hands or take your bath after?

G. Do you feel like you ingest (swallow) some water when you swim?

H. Do you often sand bath, why, and do you wash your hands or take your bath after?

I. Do you possibly ingest water or some sediment when you do?

J. Do you wash your hands before eating after harvesting biota? …… (commonly exploited biota)

K. How do you process biotabefore eating?

L. Have you ever heard or possibly known that diarrhoea can also be spread by contact with things like fish, sea sediment and seawater?

Any other comments

Appendix 1 Physicochemical Parameters of The Coastal Waters Surrounding the Selected Coastal Communities from January to June (Mean-Standard Deviation)

	Temp (°C)	pH	EC (mS/cm)	TDS (g/L)	Salinity (ppt)	DO (mg/L)	BOD (mg/L)	NO_3^- (mg/L)	PO_4^{3-} (mg/L)	SO_4^{2-} (mg/L)
					Atiteti					
Jan	28.73 ± 0.48	7.00 ± 0.08	33.46 ± 5.99	20.57 ± 3.51	20.98 ± 4.17	4.89 ± 0.61	1.72 ± 0.51	2.62 ± 0.50	0.16 ± 0.26	351.53 ± 91.06
Feb	30.75 ± 1.55	7.43 ± 0.37	37.51 ± 9.50	23.25 ± 6.00	23.87 ± 6.70	5.19 ± 0.71	3.53 ± 0.68	1.28 ± 0.97	0.06 ± 0.04	88.90 ± 5.42
Mar	31.03 ± 0.94	8.31 ± 0.20	36.55 ± 9.62	22.40 ± 5.73	23.17 ± 6.70	5.37 ± 0.82	3.06 ± 0.68	1.98 ± 0.78	0.06 ± 0.04	560.18 ± 431.52
Apr	29.78 ± 0.14	7.81 ± 0.08	36.92 ± 5.87	22.60 ± 3.42	23.23 ± 4.09	2.83 ± 0.5	5.08 ± 1.82	2.03 ± 1.25	0.23 ± 0.25	667.00 ± 159.61
May	30.47 ± 0.24	8.19 ± 0.17	38.30 ± 4.41	23.37 ± 2.69	24.32 ± 3.12	3.26 ± 0.72	5.79 ± 2.66	1.88 ± 0.78	0.11 ± 0.02	416.83 ± 123.02
June	28.05 ± 0.82	7.75 ± 0.27	46.15 ± 8.35	27.88 ± 4.81	30.02 ± 6.08	3.64 ± 0.22	7.29 ± 5.62	2.15 ± 1.34	0.04 ± 0.03	406.00 ± 130.43
Total	29.80 ± 1.35	7.75 ± 0.49	38.15 ± 8.03	23.34 ± 4.76	24.26 ± 5.68	4.20 ± 1.17	4.41 ± 3.11	1.99 ± 0.99	0.11 ± 0.16	415.08 ± 263.55
					Anyanui					
Jan	28.68 ± 0.20	9.67 ± 2.38	34.77 ± 0.15	5.32 ± 0.45	2.14 ± 0.53	2.23 ± 0.12	4.83 ± 0.12	1.67 ± 0.25	0.07 ± 0.01	260.77 ± 23.39
Feb	31.19 ± 0.20	7.74 ± 0.32	36 ± 0.46	21.93 ± 0.31	22.67 ± 0.35	2.69 ± 0.53	6.10 ± 0.38	2.53 ± 0.06	0.00 ± 0.00	93.56 ± 13.96
Mar	32.16 ± 0.24	8.14 ± 0.06	25.33 ± 0.05	15.67 ± 0.15	15.37 ± 0.15	5.68 ± 0.83	3.58 ± 0.17	0.70 ± 0.10	0.07 ± 0.01	479.53 ± 23.40
Apr	29.38 ± 0.39	7.23 ± 0.06	20.20 ± 0.26	12.50 ± 0.17	12.03 ± 0.15	3.37 ± 0.30	2.56 ± 0.39	0.83 ± 0.06	0.12 ± 0.01	480.67 ± 1.15
May	30.83 ± 0.36	8.01 ± 0.05	14 ± 0.1	8.67 ± 0.07	8.27 ± 0.29	2.22 ± 0.08	5.61 ± 0.15	1.23 ± 0.06	0.17 ± 0.01	526.0 ± 2.00
June	29.19 ± 0.24	7.57 ± 0.06	13.33 ± 0.06	8.27 ± 0.03	7.67 ± 0.06	2.90 ± 0.08	4.88 ± 0.07	0.90 ± 0.10	0.08 ± 0.03	488.6 ± 73.06
Total	30.24 ± 1.30	8.06 ± 1.15	23.94 ± 9.30	12.06 ± 5.67	11.36 ± 6.68	3.18 ± 1.27	4.59 ± 1.25	1.31 ± 0.66	0.09 ± 0.06	388.20 ± 162.64
					Anyako					
Jan	27.62 ± 1.02	10.58 ± 0.51	36.27 ± 0.25	5.52 ± 0.61	12.14 ± 1.12	3.15 ± 0.60	22.94 ± 0.39	0.66 ± 0.10	0.08 ± 0.06	370.90 ± 104.17
Feb	30.24 ± 1.13	7.67 ± 0.25	42.72 ± 1.54	25.76 ± 0.51	27.12 ± 0.60	1.56 ± 0.18	30.46 ± 3.69	0.90 ± 0.27	0.06 ± 0.03	433.63 ± 74.19
Mar	33.49 ± 0.71	7.99 ± 0.27	48.91 ± 2.08	29.63 ± 1.01	31.90 ± 1.51	4.97 ± 0.54	27.14 ± 4.64	1.59 ± 0.15	0.18 ± 0.28	906.69 ± 212.76
Apr	34.39 ± 0.47	8.00 ± 0.16	49.81 ± 2.47	30.20 ± 1.25	32.56 ± 1.83	1.70 ± 0.14	42.98 ± 2.05	1.79 ± 0.12	0.06 ± 0.03	875.78 ± 230.95
May	28.39 ± 0.71	7.35 ± 0.26	51.41 ± 10.81	28.33 ± 2.86	31.24 ± 1.16	3.74 ± 0.42	32.55 ± 1.81	1.19 ± 0.47	0.05 ± 0.03	387.56 ± 88.20
June	31.21 ± 0.44	7.50 ± 0.17	42.87 ± 1.35	26.10 ± 0.85	26.22 ± 4.42	3.52 ± 0.57	24.14 ± 3.40	1.34 ± 0.35	0.07 ± 0.01	324.89 ± 8.39
Total	30.89 ± 2.60	8.18 ± 1.15	45.33 ± 6.92	24.26 ± 8.73	26.86 ± 7.36	3.11 ± 1.27	30.03 ± 7.32	1.24 ± 0.47	0.08 ± 0.12	549.91 ± 281.06
					Mumford					
Jan	28.19 ± 0.27	8.09 ± 0.12	55.08 ± 0.57	33.82 ± 0.54	33.59 ± 0.38	3.34 ± 0.05	3.56 ± 0.15	0.53 ± 0.29	0.07 ± 0.01	1179.26 ± 129.54
Feb	25.02 ± 1.33	7.38 ± 0.11	56.67 ± 0.83	33.93 ± 0.29	37.14 ± 0.80	5.26 ± 0.88	2.66 ± 0.51	0.96 ± 0.50	0.09 ± 0.08	770.73 ± 370.58
Mar	29.77 ± 0.50	7.38 ± 0.04	55.98 ± 0.31	33.66 ± 0.05	37.33 ± 0.58	3.61 ± 0.64	2.64 ± 0.45	1.48 ± 0.32	0.05 ± 0.02	1108.74 ± 197.29

Apr	28.98 ± 0.1	7.41 ± 0.15	55.80 ± 0.14	33.46 ± 0.07	37.27 ± 0.07	4.29 ± 0.29	2.43 ± 0.32	0.73 ± 0.12	0.03 ± 0.01	974.78 ± 211.16
May	28.45 ± 0.23	8.44 ± 0.31	55.12 ± 0.27	33.09 ± 0.18	37.17 ± 0.06	3.64 ± 0.31	2.77 ± 0.56	0.78 ± 0.12	0.02 ± 0.01	1126.67 ± 84.23
June	26.05 ± 0.73	7.29 ± 0.21	55.90 ± 0.24	33.56 ± 0.16	37.12 ± 0.18	4.65 ± 0.57	2.75 ± 0.31	0.73 ± 0.48	0.06 ± 0.04	1193.78 ± 162.70
Total	27.74 ± 1.80	7.67 ± 0.47	55.76 ± 0.70	33.59 ± 0.38	37.08 ± 0.47	4.13 ± 0.85	2.80 ± 0.53	0.92 ± 0.45	0.06 ± 0.05	1058.99 ± 250.97
					Gbegbeyise Beach					
Jan	28.25 ± 0.27	8.29 ± 0.10	54.21 ± 0.31	33.60 ± 0.22	23.78 ± 1.82	3.25 ± 0.10	2.39 ± 0.27	0.44 ± 0.27	0.65 ± 0.52	1090.58 ± 117.76
Feb	27.09 ± 0.49	7.44 ± 0.08	56.17 ± 0.94	33.74 ± 0.55	36.96 ± 1.47	4.34 ± 0.44	2.74 ± 0.28	6.18 ± 1.55	0.10 ± 0.06	1058.93 ± 180.74
Mar	30.14 ± 0.16	7.35 ± 0.17	55.98 ± 0.23	33.60 ± 0.13	37.16 ± 0.19	3.06 ± 0.39	3.03 ± 0.81	3.52 ± 2.51	0.03 ± 0.02	1132.99 ± 160.95
Apr	28.48 ± 0.06	7.58 ± 0.07	52.64 ± 6.08	31.67 ± 3.45	34.77 ± 4.45	3.40 ± 0.43	3.23 ± 0.51	1.90 ± 0.90	0.44 ± 0.63	1316.33 ± 81.98
May	29.04 ± 0.32	8.24 ± 0.12	55.30 ± 0.11	33.16 ± 0.07	36.69 ± 0.09	3.92 ± 0.32	3.67 ± 0.31	2.51 ± 0.86	0.40 ± 0.48	1039.78 ± 161.18
June	25.75 ± 0.68	7.56 ± 0.27	53.60 ± 0.98	32.28 ± 0.63	35.47 ± 0.79	4.28 ± 0.44	3.11 ± 0.39	0.54 ± 0.32	0.07 ± 0.01	1106.67 ± 196.93
Total	28.12 ± 1.46	7.74 ± 0.40	54.65 ± 2.75	33.01 ± 1.59	34.14 ± 5.15	3.71 ± 0.62	3.03 ± 0.60	2.68 ± 2.35	0.30 ± 0.44	1124.21 ± 173.73
					Gbegbeyise Estuary					
Jan	30.12 ± 0.07	5.25 ± 0.12	12.33 ± 0.81	1.84 ± 0.05	22.51 ± 0.35	7.79 ± 0.15	7.18 ± 0.24	19.40 ± 4.87	1.27 ± 0.47	283.26 ± 10.62
Feb	34.25 ± 0.28	2.58 ± 0.13	7.46 ± 1.83	4.70 ± 1.15	4.10 ± 1.04	3.72 ± 0.70	26.01 ± 0.39	2.23 ± 0.06	1.03 ± 0.34	2633.33 ± 860.72
Mar	33.79 ± 0.86	2.56 ± 0.05	7.31 ± 0.84	3.76 ± 0.37	3.40 ± 0.30	1.24 ± 0.02	25.03 ± 0.72	0.73 ± 0.23	1.42 ± 0.17	996.43 ± 23.46
Apr	28.44 ± 0.19	3.30 ± 0.33	22.20 ± 3.76	13.73 ± 2.33	11.07 ± 5.42	4.95 ± 0.58	34.56 ± 2.00	7.77 ± 1.18	3.16 ± 0.19	987.67 ± 1.53
May	29.43 ± 0.10	8.25 ± 0.02	55.17 ± 0.23	33.10 ± 0.17	36.60 ± 0.17	3.83 ± 0.05	22.44 ± 0.32	12.6 ± 0.20	0.73 ± 0.01	621.00 ± 1.00
June	33.29 ± 0.64	5.89 ± 1.03	4.31 ± 0.44	2.89 ± 0.33	2.57 ± 0.50	1.75 ± 0.05	69.29 ± 1.65	46.87 ± 57.1	0.86 ± 0.02	620.00 ± 2.00
Total	31.68 ± 2.40	4.64 ± 2.15	18.13 ± 18.10	10.0 ± 11.40	13.37 ± 12.96	3.88 ± 2.24	30.75 ± 19.64	14.93 ± 25.38	1.41 ± 0.87	1023.62 ± 836.03

Appendix 2 Coliform (TCC and *Escherichia coli* (*E. coli*) count in water samples (mean-standard deviation)

	TCC (CFU/100ml)	*E. coli* (CFU/mL)
	Atiteti	
Jan	850 ± 526.57	0
Feb	675 ± 607.72	0
Mar	2750 ± 2888.38	0
Apr	2275 ± 1309.49	424 ± 56.20
May	1892 ± 1813.81	0
Jun	4008 ± 6930.10	0
Total	2075 ± 3303.76	71 ± 270.68
	Anyanui	
Jan	1267 ± 550.76	0
Feb	333 ± 57.74	0
Mar	2167 ± 1674.32	0
Apr	1567 ± 1950.21	0
May	1633 ± 1965.54	0
Jun	2167 ± 1101.51	0
Total	1522 ± 1349.32	0
	Anyako	
Jan	3167 ± 1988.72	0
Feb	5778 ± 3964.14	0
Mar	4522 ± 3405.06	0
Apr	2256 ± 1516.67	0
May	8433 ± 11407.67	0
Jun	73000 ± 106474.18	333 ± 559.02
Total	16193 ± 48964.06	56 ± 250.78
	Mumford	
Jan	3889 ± 7012.03	0
Feb	1422 ± 1297.86	0
Mar	2222 ± 2358.91	0
Apr	2022 ± 2116.47	0
May	8567 ± 7547.68	0
Jun	134311 ± 362880.74	66894 ± 181547.85
Total	25406 ± 149388.68	11149 ± 74888.41
	Gbegbeyise Beach	
Jan	5378 ± 8330.78	0
Feb	189 ± 293.45	0
Mar	689 ± 788.11	297 ± 458.11
Apr	21733 ± 42240.86	7078 ± 14258.49
May	61056 ± 78530.20	0
Jun	1453400 ± 4329998.62	725007 ± 2165628.06
Total	257074 1767291.84	122064 ± 884326.59
	Gbegbeyise Estuary	
Jan	323333 ± 55075.71	0
Feb	273333 ± 30550.50	107000 ± 37510.00
Mar	17733 ± 11498.41	8567 ± 5093.46
Apr	760000 ± 592705.66	345667 ± 348907.34
May	62333 ± 67485.80	0
Jun	15333333 ± 11930353.45	42333333 ± 71591433.38
Total	2795011 ± 7080983.25	7132428 ± 29417833.62

Appendix 3 Distribution of identified bacterial isolates in biota samples per selected communities

Isolates from Biota Samples						
Isolate Number (n) and Percentage						
Isolates (n)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Atiteti (Bogue fish – *Boops boops*)						
E. Coli	-	-	0	0	-	-
E. faecalis	-	-	25(3)	0	-	-
Salmonella	-	-	0	0	-	-
Shigella	-	-	0	0	-	-
Vibrio spp.	-	-	25(3)	75(3)	-	-
Other coliforms	-	-	50(6)	25(1)	-	-
Total	0	0	12	4	0	0
Anyanui (Mangrove oyster - *Crassostrea gasar*)						
E. Coli	0	0	12.5(1)	0	14.29(1)	0
E. faecalis	0	0	37.5(3)	0	0	0
Salmonella	0	0	25(2)	0	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	100(1)	0	0	100(2)	28.57(2)	0
Other coliforms	0	100(6)	25(2)	0	57.14(4)	100(2)
Total	1	6	8	2	7	2
Anyako (Bogue fish – *Boops boops*)						
E. Coli	0	0	0	25(3)	0	0
E. faecalis	27.27(3)	25(2)	0	25(3)	0	35.29(6)
Salmonella	0	0	0	0	16.67(1)	0
Shigella	0	0	0	0	0	0
Vibrio spp.	54.55(6)	0	60(3)	0	50(3)	0
Other coliforms	18.18(2)	75(6)	40(2)	50(6)	33.33(2)	64.71(11)
Total	11	8	5	12	6	17
Mumford (*Priacanthus arenatus* and *Chloroscombrus chrysurus*)						
E. Coli	15.38(2)	0	-	0	37.5(3)	-
E. faecalis	23.08(3)	0	-	42.86(3)	0	-
Salmonella	0	0	-	0	0	-
Shigella	0	0	-	0	0	-
Vibrio spp.	15.38(2)	0	-	14.29(1)	37.5(3)	-
Other coliforms	46.15(6)	0	-	42.86(3)	25(2)	-
Total	13	0	0	7	8	0
Gbegbeyise (Atlantic Ghost Crab/Ocypode)						
E. Coli	-	-	0	0	-	0
E. faecalis	-	-	28.57(2)	0	-	66.67(2)
Salmonella	-	-	0	0	-	0
Shigella	-	-	0	0	-	0
Vibrio spp.	-	-	42.86(3)	100(3)	-	0
Other coliforms	-	-	28.57(2)	0	-	33.33(1)
Total	0	0	7	3	0	3

Appendix 4 Distribution of identified bacterial isolates in water samples in the selected communities

Isolates from Water Samples						
	Isolate Percentage and Number (n)					
Isolates (n)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
			Atiteti Beach			
E. Coli	0	0	0	17.14(6)	0	0
E. faecalis	0	0	4(1)	2.86(1)	5.26(1)	24(6)
Salmonella	0	0	0	8.57(3)	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	43.8(7)	23.08(3)	28(7)	17.14(6)	21.05(4)	24(6)
Other coliforms	56.25(9)	76.92(10)	68(17)	54.29(19)	73.68(14)	52(13)
Total	18	13	25	35	19	25
			Anyanui Mangrove			
E. Coli	0	0	0	0	0	0
E. faecalis	0	0	0	0	0	0
Salmonella	0	0	0	0	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	50(6)	66.67(6)	60(9)	33.33(3)	33.33(3)	0
Other coliforms	50(6)	33.33(3)	40(6)	66.67(6)	66.67(6)	100(9)
Total	12	9	15	9	9	9
			Anyako Fishing Lagoon			
E. Coli	0	0	0	0	0	12.50(3)
E. faecalis	0	3.70(1)	6.90(2)	0	6.67(1)	29.17(7)
Salmonella	0	0	0	23.53(4)	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	46.15(6)	44.44(12)	31.03(9)	52.94(9)	33.33(5)	12.50(3)
Other coliforms	53.85(7)	51.85(14)	62.07(18)	23.53(4)	60(9)	45.83(11)
Total	13	27	29	17	15	24
			Mumford Beach			
E. Coli	0	0	0	0	0	25(6)
E. faecalis	0	0	0	0	0	25(6)
Salmonella	0	0	0	20(3)	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	40(6)	23.08(3)	42.86(9)	60(9)	34.62(9)	12.5(3)
Other coliforms	60(9)	76.92(10)	57.14(12)	20(3)	65.38(17)	37.5(9)
Total	15	13	21	15	26	24
			Gbegbeyise Beach			
E. Coli	0	0	35.29(6)	15(3)	0	17.14(6)
E. faecalis	0	33.33(3)	11.76(2)	20(4)	15(3)	17.14(6)
Salmonella	0	0	0	0	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	0	33.33(3)	17.65(3)	30(6)	30(6)	17.14(6)
Other coliforms	100(3)	33.33(3)	35.29(6)	35(7)	55(11)	48.57(17)
Total	3	9	17	20	20	35
			Gbegbeyise Estuary			
E. Coli	0	21.43(9)	25(9)	21.43(9)	0	25(9)
E. faecalis	0	21.43(9)	25(9)	14.29(6)	100(9/9)	25(9)
Salmonella	0	0	0	0	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	60(9)	21.43(9)	25(9)	21.43(9)	0	25(9)
Other coliforms	40(6)	35.71(15)	25(9)	42.86(18)	0	25(9)
Total	15	42	36	42	9	36

Appendix 5 Distribution of identified bacterial isolates in Sediment samples in the selected community

Isolates from Sediment Samples						
Isolate Percentage and Number (n)						
Isolates (n)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Atiteti						
E. Coli	0	0	0	0	0	0
E. faecalis	18.18(2)	11.76(2)	25(2)	0	25(1)	25(1)
Salmonella	27.27(3)	0	0	0	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	27.27(3)	17.65(3)	25(2)	50(3)	75(3)	75(3)
Other coliforms	27.27(3)	70.59(12)	50(4)	50(3)	0	0
Total	11	17	8	6	4	4
Anyanui						
E. Coli	0	0	0	0	0	10(3)
E. faecalis	33.33(9)	37.5(9)	50(9)	69.23(9)	0	30(9)
Salmonella	0	0	0	0	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	33.33(9)	37.5(9)	50(9)	30.77(4)	100(6)	30(9)
Other coliforms	33.33(9)	25(6)	0	0	0	30(9)
Total	27	24	18	13	6	30
Anyako						
E. Coli	0	0	0	0	28.57(4)	13.33(4)
E. faecalis	56.25(9)	27.27(6)	50(9)	42.86(9)	28.57(4)	30(9)
Salmonella	0	0	0	0	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	25.00(4)	27.27(6)	50(9)	42.86(9)	42.86(6)	20(6)
Other coliforms	18.75(3)	45.45(10)	0	14.29(3)	0.00	36.67(11)
Total	16	22	18	21	14	30
Mumford						
E. Coli	0	0	15(3)	50(1)	0	0
E. faecalis	10(1)	0	10(2)	0	0	42.86(6)
Salmonella	20(2)	0	0	0	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	30(3)	66.67(2)	15(3)	0	60(6/1)	21.43(3)
Other coliforms	40(4)	33.33(1)	60(12)	50(1)	40(4)	35.71(5)
Total	10	3	20	2	10	14
Gbegbeyise						
E. Coli	0	0	17.65(3)	0	0	0
E. faecalis	0	60(3)	11.76(2)	28.57(4)	41.67(5)	53.33(8)
Salmonella	0	0	0	0	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	60(3)	40(2)	35.29(6)	42.86(6)	50(6)	40(6)
Other coliforms	40(2)	0	35.29(6)	28.57(4)	8.33(1)	6.67(1)
Total	5	5	17	14	12	15
Gbegbeyise Estuary						
E. Coli	0	0	0	0	0	0
E. faecalis	40(6)	42.86(9)	0	18.75(3)	0	50(9/1)
Salmonella	0	0	0	0	0	0
Shigella	0	0	0	0	0	0
Vibrio spp.	60(9)	42.86(9)	50(9)	43.75(7)	28.57(6)	50(9)
Other coliforms	0	14.29(9)	50(9)	37.5(6)	71.43(15)	0
Total	15	21	18	16	21	18

PLATES

Plate 1: Sea snail (Pugilina morio)- Anyako

Plate 2: Small-sized tilapia (Oreochromis) - Anyako

Plate 3: Mangrove oyster (Crassostrea gasar) – Anyanui

Plate 4: Small yellow-tailed scad fish Anyako - Mumford

Plate 5: Chachawe (still identifying) -Mumford

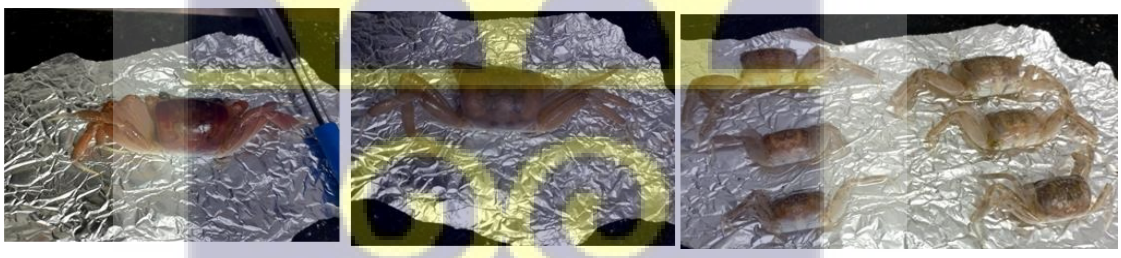


Plate 6: Atlantic ghost crab/Ocypode - Opetekwei, Gbegbeyese

Plate 7: Water sampling

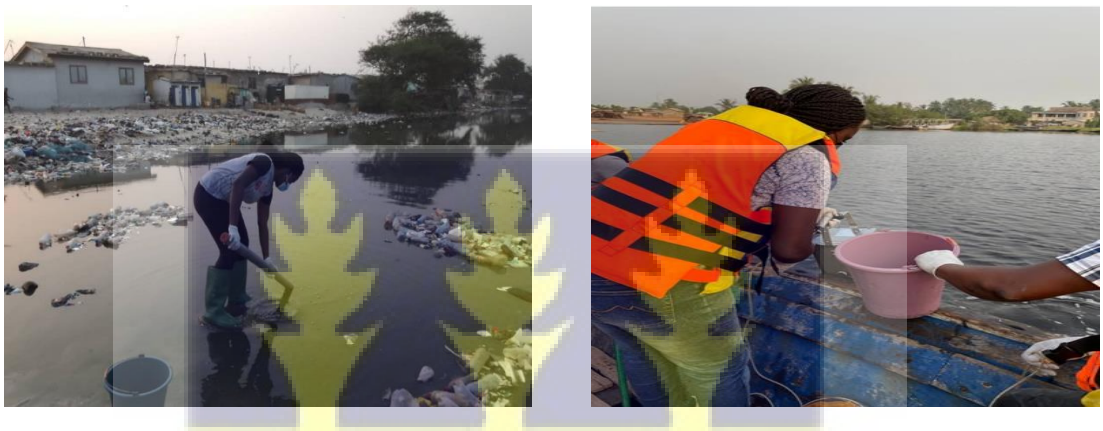


Plate 8: Sediment sampling at Gbegbeyise and Anyanui mangrove river

Plate 9: Laboratory Analysis at Noguchi and Ecological Laboratory, University of Ghana

Plate 10: Focus group discussion sessions

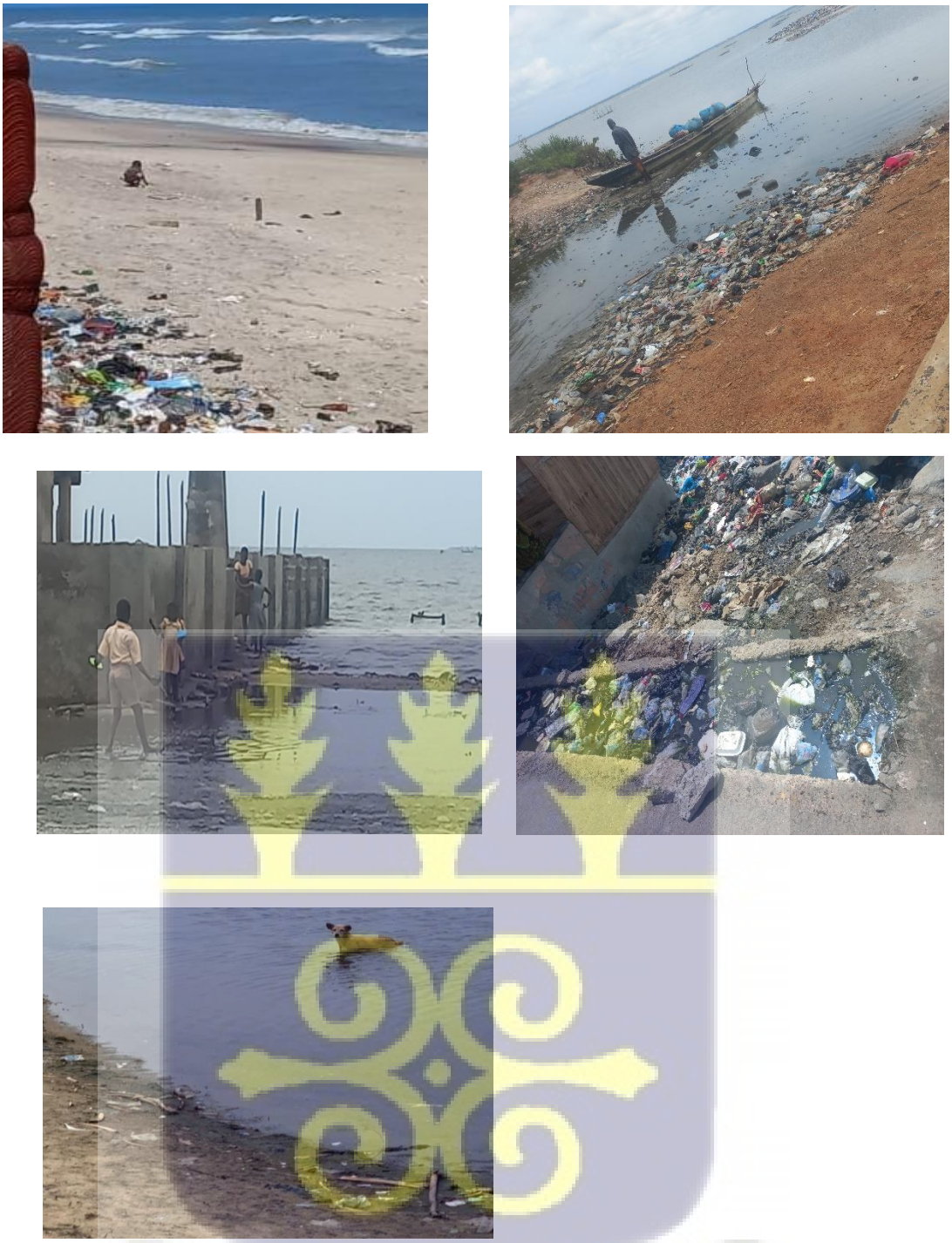
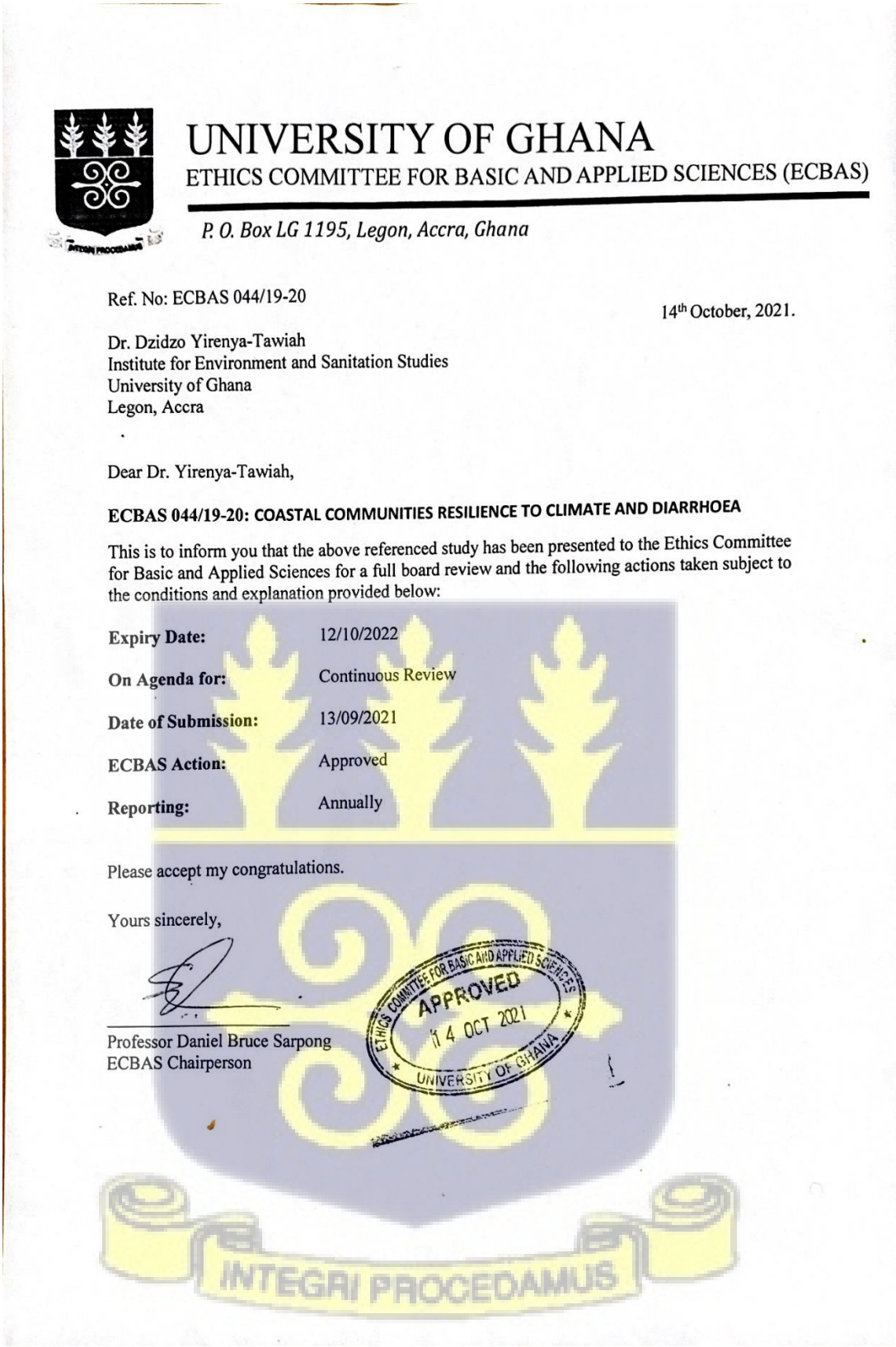


Plate 11: Some poor sanitary conditions observed



UNIVERSITY OF GHANA
ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES (ECBAS)
P. O. Box LG 1195, Legon, Accra, Ghana

Ref. No: ECBAS 044/19-20

14th October, 2021.

Dr. Dzidzo Yirenya-Tawiah
Institute for Environment and Sanitation Studies
University of Ghana
Legon, Accra

Dear Dr. Yirenya-Tawiah,

ECBAS 044/19-20: COASTAL COMMUNITIES RESILIENCE TO CLIMATE AND DIARRHOEA

This is to inform you that the above referenced study has been presented to the Ethics Committee for Basic and Applied Sciences for a full board review and the following actions taken subject to the conditions and explanation provided below:

Expiry Date:	12/10/2022
On Agenda for:	Continuous Review
Date of Submission:	13/09/2021
ECBAS Action:	Approved
Reporting:	Annually

Please accept my congratulations.

Yours sincerely,

Professor Daniel Bruce Sarpong
ECBAS Chairperson

ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES
APPROVED
14 OCT 2021
UNIVERSITY OF GHANA

INTEGRI PROCEDAMUS

Plate 12: Proof of ethical clearance for community entry and study commencement under the auspices of the C2RCD project