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Institute of Water  
and Energy Sciences

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**INSTITUTE FOR WATER AND ENERGY SCIENCES**  
**(Including CLIMATE CHANGE)**



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Cities: A Case Study of Accra – Ghana**

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## **DEDICATION**

This work is dedicated to my family and love ones for their constant support.

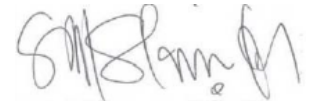
## STATEMENT OF THE AUTHOR

I hereby declare that this thesis is the original outcome of my research, has been realized to the best of my knowledge and ability. This work has not been submitted for any previous degree or an award. The experimental work is almost entirely my own work; the collaborative contributions have been indicated clearly and acknowledged. Due references have been provided on all supporting literatures and resources.

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## **LIST OF ABBREVIATIONS**

EPA- Environmental Protection Agency  
WHO- World Health Organization  
UNEP- The United Nations Environment Programme  
GIS- Geographical Information Systems  
GPS- Global Positioning System  
E. coli- Escherichia coli  
DRC- Democratic Republic of Congo  
UN-HABITAT- The United Nations Human Settlements Programme  
Cu- Copper  
Zn-Zinc  
Al- Aluminum  
TSS- Total suspended Solids  
TDS- Total Dissolved Solids  
USGS- United States Geological Survey  
BOD- Biological Oxygen Demand  
COD- Chemical oxygen demand  
NWP- National Water Policy  
NDWQMFG- National Drinking Water Quality Management Framework for Ghana  
GSA – Ghana Standards Authority  
WRC- Water Resources Commission  
GWCL – Ghana Water Company Limited  
GMS- Groundwater Management strategy  
CWSA- Community Water and Sanitation Agency  
PURC- Public Utilities Regulation Commission  
GQAU- Groundwater Quality Assurance Unit  
UV- Ultra Violet  
FNU - Formazin Nephelometric Units  
NTU - Nephelometric Turbidity Unit  
ETA- Ethanolamine  
SD- Standard Deviation

CV- Coefficient of Variation

DF- Degree of Freedom

ESP- Environmental Sanitation Project

MLG- Ministry of Local Government

NCWSP- National Community and Sanitation Project

CFU- Colony Forming Units

Slum 1- Nima

Slum 2- Sabon Zongo

Slum 3- Chorkor

Slum 4- Jamestown

Slum 5 – Pantang- Abokobi Landfill community

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## ABSTRACT

Population influx in African cities have caused the emergence of slums. Most urban slum dwellers depend on groundwater sources because of their availability and affordability. Due to the dense living conditions of the slums, wells and boreholes are situated in locations that expose the groundwater to possible contamination. A study was therefore conducted to determine the effects of urbanization on groundwater quality in Accra. A mixed method research design was used whereby interviews were conducted among slum residents in order to acquire information about groundwater usage. Twenty (20) groundwater samples were taken from five (5) slums within the city of Accra for laboratory analysis in order to assess the quality of the water. The coordinates of each sampling location were recorded using GPS. The water samples were analyzed for 27 physiochemical water quality parameters and two (2) microbiological indicators. An analysis of variance (ANOVA) was conducted to assess the difference in water quality parameters between slums. Geostatistical analysis was also conducted to map the extent and distribution of water quality parameters among slums. The results showed that 15 out of 27 water quality parameters were significantly different between slums ( $p < 0.050$ ). Microbiological indicators were also significantly different among slums with p-values such as; *E. coli* ( $p = 0.0067$ ) and Total coliform ( $p = 0.0003$ ). Four out of the 5 slums were significantly experiencing lead (Pb) poisoning in the groundwater. The mean lead concentrations for these slums were 0.25mg/l, 1.00, 0.25 and 1.5mg/l, respectively for Nima, Chorkor, Jamestown and Pantang. The results were above the WHO lead limit of 0.01mg/l. Chorkor and Sabon Zongo also had salt producing physiochemical parameters which were above the WHO permissible value. The mean values recorded for the salt parameters were 222.50 and 462.50mg/l for Ca, 177.50 and 255.00mg/l for Mg, 727.3 and 1063.4mg/l for  $\text{Cl}^-$ , and 270.37, 472.00, 690.16mg/l for Na. Nima, Sabon Zongo and Jamestown were using groundwater that is exposed to high levels of nitrate. The results also show the presence of manganese exceeding WHO value in the groundwater of Nima, Chorkor and Pantang. All the groundwater samples from the 5 slums were bacterially contaminated which is a possible indication of faecal matter presence in the water. A geospatial mapping of water quality parameters showed that slums closer to the sea were high in dissolved ions thereby implying possible salt water intrusion. The mapping also showed that slums closer to major landfills were experiencing more groundwater contamination. The results of the study imply that the environment and location of wells contribute immensely to the quality of groundwater produced. A policy brief and framework have been developed to fill in the gaps for quality assurance in Ghana water policy.

Keywords: Urbanization, Groundwater quality, Slums.

## Résumé

L'accroissement accéléré des populations en zone urbaine en Afrique a causé l'émergence des bidonvilles. La plupart des bidonvilles s'alimentent avec eaux souterraines en raison de leur disponibilité et de leur prix abordable. En raison de la densité des conditions de vie dans les bidonvilles, les puits et les forages sont situés à des endroits susceptibles d'être exposés à une contamination éventuelle. Un modèle de recherche à méthode mixte a été utilisé dans le cadre duquel des entretiens ont été menés auprès de résidents de bidonville dans d'autres pays pour obtenir des informations sur l'utilisation des eaux souterraines. Vingt (20) échantillons d'eau souterraine ont été prélevés dans cinq (5) bidonvilles de la ville d'Accra. Les coordonnées de chaque lieu d'échantillonnage ont été enregistrées à l'aide d'un GPS. 27 paramètres physicochimiques étaient sur chaque échantillon et deux (2) indicateurs microbiologiques. Une analyse de variance (ANOVA) a été réalisée pour évaluer la différence de paramètres de qualité de l'eau entre les bidonvilles. Une analyse géostatistique a également été réalisée pour cartographier l'étendue et la répartition des paramètres de qualité de l'eau dans les bidonvilles. Les résultats ont montré que 15 paramètres de qualité de l'eau sur 27 étaient significativement différents entre les bidonvilles ( $p < 0,050$ ). Les indicateurs microbiologiques étaient également très différents parmi les bidonvilles présentant des valeurs  $p$  telles que *E. coli* ( $p = 0,0067$ ) et coliformes totaux ( $p = 0,0003$ ). Quatre des cinq bidonvilles ont été gravement intoxiqués par le plomb (Pb) dans les eaux souterraines. Les concentrations moyennes de plomb étaient respectivement de 0,25 mg / l, 1,00, 0,25 et 1,5 mg / l pour Nima, Chorkor, Jamestown et Pantang. Les résultats obtenus dépassent les normes de l'OMS, fixée à 0,01 mg / l. Chorkor et Sabon Zongo avaient également des paramètres physicochimiques producteurs de sel supérieurs à la valeur admissible par l'OMS. Les valeurs moyennes enregistrées pour les paramètres de sel étaient 222,50 et 462,50 mg / l pour Ca, 177,50 et 255,00 mg / l pour Mg, 727,3 et 1063,4 mg / l pour Cl<sup>-</sup> et 270,37, 472,00 et 690,16 mg / l pour Na. Les eaux de Nima, Sabon Zongo et Jamestown étaient exposées à de fortes concentrations de nitrate. Les résultats montrent que la concentration en manganèse de Nima, Chorkor et Pantang dépassait les normes de l'OMS. Tous les échantillons d'eau souterraine des 5 bidonvilles étaient contaminés par des bactéries, ce qui pourrait être causée par la présence de matières fécales dans l'eau. La présence des ions dissous a été identifiée sur la cartographie des bidonvilles très proches de la mer, ceci peut impliquer la possibilité d'intrusion d'eau salée. La cartographie montra aussi que les bidonvilles plus proches de décharges majeures étaient davantage contaminées par les eaux souterraines. Les résultats de l'étude montrent le type et la qualité du sol influencent la qualité de eaux souterraine. Un document d'orientation et un cadre ont été élaborés pour combler les lacunes en matière d'assurance de la qualité dans la politique de l'eau au Ghana.

Mots-clés : Urbanisation, qualité des eaux souterraines, bidonvilles.



## **CHAPTER ONE**

### **1.0 INTRODUCTION**

#### **1.1 Background**

Urbanization is at its peak in today's Africa as most people migrate to cities for greener pastures. Among the developing countries in the world, African cities accounts for the largest growth in urban population growth over the last two decades at 3.5% per year. The rate is projected to hold up to 2050 with the cities representing up to 85% of the total population (Group, 2012). The rapid growth of African urban centers has changed the demographics of city landscape and settlements thereby causing emergence of slums. This change in livelihood has put enormous pressure on the residential setting of urban centers, causing people to recede in slums and dumpsites with more than 60% of African city dwellers lacking access to water supply and sanitation facilities. In quest for having water for survival, the inhabitants of these areas depend on dug wells and boreholes for domestic water uses. In most cases, these types of waters are prone to contamination and pollution through leachates from landfills (DaoliangLi et al., 2018). The residents of these urban slums use sanitation systems such as pit latrines, open defecation and improper solid waste disposal among others. There is increased level of pollution of the groundwater sources through deep percolation and runoff for open wells. This effect is aggravated by the proximity of the wells to deteriorated sanitation systems (Nyarko, 2008).

Groundwater, serving as the major source of drinking water in the cities, is highly threatened as the aquifer in the major African cities is also used as the repository for human and solid waste. This has caused the degradation of the water quality to be less than the set standards for human consumption. Contaminants such as fecal coliform, fluoride, acidic contents, arsenide and lead can be introduced into the groundwater through leaky underground systems, and accidental spills in the case of areas close to industrial zones. Low quality drinking water results in health consequences such as cholera, diarrhea, typhoid, infections and among others (Cronin, 2007). The quality of groundwater is as relevant as the quantity because this water is made up of different sources from several aquifers with changing constituents (Wakode, 2014). The knowledge of the occurrence of the physical, biological and chemical elements in the groundwater is therefore essential for the assessment of the quality of water.

Therefore, in order to ensure delivery of quality water, UNEP and WHO (1996), argued that it is not important to only have access to water in adequate quantities, but the water also needs to be

potable and of standard quality to maintain health. The World Health Organization therefore has a set of guidelines for drinking water quality which was formed as an authoritative ground for setting national standards for water safety to support public health (WHO W. H., 2017). This study intends to conduct analysis of the quality of groundwater obtained in heavily populated areas of Accra, using the standards of World Health Organization (WHO) as a comparison guideline

## **1.2 Problem Statement**

Population explosion in Accra has increased the dependency of suburbs of the city on well water due to lack of access to pipe borne water (Esenam, 2007). Most of the residents in these peri-urban centres lack pipe water systems. In addition, they have limited access to land space and have no proper sanitation systems. The prevalence of slums has therefore pushed city dwellers to drill boreholes and wells within the unsafe zones of pit latrines, solid waste dumpsites and near municipal septic tanks (Nsiah, 2015). The dense nature of the living conditions in urban slums expose the constructed wells and boreholes to increased contamination and reduced quality for human consumption. The siting of wells close to landfills has exposed the drinking water source to various forms of groundwater contamination leading to extreme health consequences such as cholera and typhoid which are very rampant in the slum suburbs of Accra.

## **1.3 Objective**

The main aim of the study is to assess the effect of urbanization on the quality of groundwater consumed in slums near landfills in Accra. This aim will be achieved by undertaking the following specific tasks:

1. Collect water samples and map the position of wells and boreholes using GPS (Global Positioning System) at twenty (20) locations in five (5) slums of the city.
2. Determine the microbial composition of the water samples
3. Determine the physiochemical properties of the water.
4. Compare water quality indicators with the standard guidelines of World Health Organization
5. Suggest a policy brief for guiding the use of groundwater in slum urban centers

## **1.4 Research questions**

1. How are wells and boreholes are distributed in the slums of the city? What is the driver(s) of this distribution?

2. Is the groundwater in slums microbially contaminated? What is the extent of such a contamination?
3. Is the groundwater in slums physiochemically contaminated? What is the extent of such a contamination?
4. How the quality of water in wells and boreholes of Accra slums relates to the standard guidelines of World Health Organization? What is the implication on the health of inhabitants?
5. What policy measures can be put in place to ensure the safety of groundwater users in the slums of Accra?

### **1.5 Significance of Study**

The research provided information on the quality of groundwater used in slums specifically landfill prone urban areas in terms of the chemical and biological components. The data obtained, and the provided policy framework will serve as guide for government in regulating and protecting quality groundwater for people in cities.

### **1.6 Limitation of study**

The challenge encountered during the study is the one- season sampling due to the time constraint. Sampling during wet season and dry seasons would have broadened the research scope in the perspective of climate as a contributing factor on groundwater quality. Also, the indigenes of some slums were also not cooperative in the survey and sampling exercise. In the midst of these challenges the researcher overcame all and conducted a study in the frame of the stated objectives to highlight the effects of urbanization on groundwater quality.

## **CHAPTER TWO**

### **2.0 LITERATURE REVIEW**

#### **2.1 Introduction**

Availability of quality water is a vital requirement for survival, but the case is gloomy in the crowded cities of Africa with which Accra (Ghana) not being an exception. This unexpected turn of things has caused increased dependence on alternative sources of groundwater such as wells and boreholes which are situated in contamination prone areas (Nkansah, 2010). Various studies have been conducted in the domain to assess the quality of water used by indigenes of the densely populated cities. The groundwater quality in cities of Timbuktu and Lichinga of Mali were studied by (Cronin, 2007) and the results indicated that urbanization has contributed to the increased levels of nitrate and chloride concentrations in the groundwater used. This was mainly due to on-site sanitation systems. High levels of *E. coli* were also found in the water used by the people for drinking (Cronin, 2007). Nkansah et al (2010), in their assessment of hand-dug wells in the Kumasi metropolis (the second most populated city in Ghana), concluded that the total hardness, pH, manganese (Mn) and electrical conductivity (EC) were not within the permissible range of the guidelines of World Health Organization, thereby exposing the inhabitants to negative health impacts. Human induced activities such as illegal waste dumps and poor sanitary practices attributed to urbanization were recorded as the causes of the high pH and general acidic nature of the 15 well samples in the Onitsha North local Government area of Nigeria (Anukwonke, 2014). In the assessment of groundwater quality and urban water provision in the Taifa suburb of Accra, Nyarko (2008) highlighted through GIS tools, the presence of heavy metals such as fluorine alongside nitrate content in 30% of the water samples analyzed. Human and animal fecal contamination were also recorded with an overall conclusion that the groundwater of the region is below the permissible requirement of WHO, hence not recommended for human consumption. In other continents such as Asia, a study was conducted in Hyderabad (India) to assess the impacts of urbanization on groundwater resources using GIS. In that study, the investigation of the groundwater used for drinking showed traces of chromium, iron, lead and increased levels of recharge of the aquifer from sewage and solid waste leachates (Wakode, 2014). On the contrary to earlier researches, the quality of groundwater studied by Quarcoo (2014) in the Amasaman suburb of Accra, indicated that the quality standards fell within the permissible range of WHO except for the minimal presence of coliform bacteria which implied exposure to human waste leachates (Quarcoo G., 2014). In the Kumasi metropolis of Ghana, the quality of groundwater in the face of

urbanization have experienced reduction as expressed in terms of the presence of bacteria. This has led to recorded cases of dysentery, cholera and diarrheal (Mohammed, 2004).

## **2.2 Urbanization in Africa**

Africa has a population of 1.216 billion inhabitants and this census is projected to double by 2050 at a growth rate of 3.9% per year. The greater percentage (80%) of the increase occur in the urban centres, especially slums. The fastest growing cities in Africa include: Lagos-Nigeria, Kinshasa-DRC, Cairo- Egypt, Luanda- Angola, Nairobi- Kenya and Khartoum- Sudan. Among these cities there is high level of slum creation and dependence on unsafe water and sanitation facilities with Lagos and Nairobi having the biggest slums in Africa (Muggah Robert et al, 2018). The continent with the fastest rate of urbanization is Africa with increasing pressure on urban infrastructure. In as much as many are of the view that urbanization increases productivity, there is negative impact on the living state of city dwellers. These results in water shortages and complete lack of access to potable water and other social amenities. A typical case is the city of Bamako, Mali whose population of 3.6 million is ten times what it was in 1960 (Campbell, 2018). Although African's urbanization rate is similar to other continents, the reality of the urban growth is just an expansion of urban land into peri-urban centres and proliferation of slums. Most of the urban expansion is branded by unplanned and unregulated growth in settlement and infrastructure deficit (Güneralp, 2017). The results of the unpredicted growth have caused an increase in water demand. As water demand increases, cities are forced to depend on extraction of groundwater which is cheap but prone to contamination. (Jacobsen, 2013). The projected urban continent expansion is divided into five regions but for the purpose of this study, much attention is given to West Africa, specifically the slums in Accra, Ghana.

## **2.3 Waste management in Africa**

Extreme rate of urbanization in Africa contributes immensely to people's consumption and production of waste. 90% of waste generated in Africa is disposed on the land either controlled or uncontrolled dumpsites or landfills with only 4% recycled (Godfrey, 2018). The amount of waste generated by a country is proportional to the population and income capacity of the country. Improper management of waste is dangerous to the environment and waste such as landfills and sewage linkages are direct contaminants of groundwater (Bello et al., 2016). The situation is not different in most sub-Saharan African countries like South Africa, Zimbabwe, Zambia, and Ghana

as rubbish dumps are over the cities without any proper management. The consequences of improper waste management have no limits and it contaminates the environment especially groundwater through leachates (Adu-Boahen, 2014). Most of the waste generated in urbanized cities of Africa is mainly municipal waste which consist of trash and garbage. The representation of Africa in the five regions, the cities with the highest producer of municipal solid waste are North (Cairo), South (Johannesburg), West (Lagos), Central (Kinshasa) and East (Nairobi) (Emenike, 2013). The prominent problem of African waste management is the collection and treatment of waste generated by the population. There is no organized system of collection and treatment especially in the slums and ghettos of the city. The method of collection of waste in African cities is mainly using trash vehicles and dustbins. This is usually not done on daily basis but after it piled up for days. The collection and transportation of solid waste in Ghana and Nigeria is executed by private companies who collect the waste at a fee thereby encouraging disposal at open land mostly by poor people. The destination of the waste is at the outskirts of the city where most slums are located. The inhabitants of these slums suffer the consequence of the untreated waste. Management of waste is challenging in African cities but it difficult in the informal settlement of the city which constitute 62% of the settlement in sub- Sahara Africa (UN HABITAT, 2014).

Waste management infrastructure is largely not available in slum areas of Africa. Establishment and improvement in infrastructure are needed to reduce the amount of waste that is left to pollute the environment. In a typical African setting, the gap between waste management policies and the actual waste management practice is wide due to non- existences of management facilities and capital (Economic Commission for Africa, 2015). Some management techniques such as production of energy from waste and reduction of waste to compost for agriculture is been practiced in some African countries like Egypt and South Africa. The issue with landfill waste which is pre-dominant in sub- Sahara Africa is still persistent and mostly responsible for groundwater contamination.

### **2.3 State of Slums and Urbanization in Accra**

Urbanization in Ghana is rapidly on the rise as 51.9% of the population lives in urban areas and it is projected to reach 72.3% in 2050. Accra is the capital city of Ghana with a current population of 4.6 million people and it is ranked as the 11<sup>th</sup> biggest cities in Africa (Review, 2019). The alarming rate of urbanization in the city has put pressure on infrastructure and settlements thereby causing proliferation of major slums in the country (Okyere S.A., 2018). A slum is group of people who

live in a clustered and informal settlements without easy access to potable water and improved sanitation (UN-HABITAT, 2006). The slums in Accra include old Fadama. Nima, Ashiaman, Agbobloshie, Sodom and Gomorrah, chorkor, among others. Most of the slums in Accra have become the dumping site for municipal waste and digital waste. A typical case of digital waste site is Sodom and Gomorrah which is final house of electronic waste from all around the city. It has a population of 50, 000 inhabitants with no access to water or sewage systems (Adjei, 2014). The health of slum residents in Accra is highly threatened as they lack access to toilet facilities and safe water. The rubbish dumps located in Accra's biggest slum (Nima) pose a health problem as people extract groundwater from the same vicinity of the waste dump (Oppong J. R., 2014).

## **2.5 Solid Waste Management in Ghana (existing management scheme)**

Waste management is a major challenge for the city of Accra and despite various attempts made by the government of Ghana to keep the situation under control, residents of informal settlements are the recipients of the negative impact. Management of waste in Ghana have always received a lukewarm attitude from Government associated with lack of techniques, resources, skill labour and enforced regulations (Agyepong, 2018). The available systems used in Ghana for waste management includes; disposing solid waste on sanitary and unsanitary landfills, composting, recycling, and incineration to produce energy (Samwine T., 2017). It basically involves house to house collection of waste to a central container. Private companies collect the waste from the central containers to a municipal landfill or dumpsite, a deserted land at the outskirts. Landfilling remains the most common method of waste disposal in Accra. The devastating effect on the environment is rampant due to the nature of the open system, scavenging and lack of leachate control (Agyepong, 2018). Accra generates about 1.3 million metric tons of solid waste per year

mostly made up of organic matter. The collection, transportation and disposal of waste remains a challenge for the major cities in the country. Contamination of water bodies from the major landfill in Weija- Accra contributes to the health hazards from stench, air contamination and garbage - choked drains. Waste disposal is mainly informal which consist of stone quarry sites, natural depressions on the land, mining pits and artificial holes. Open burning of the landfill occurs in the dry season (EPA, 2010). The available waste management plant processes 500 metric tons of waste which is mainly made up plastic waste and the rest of the waste is left to decompose without any management scheme for groundwater protection (Anarfi, 2015). Other indiscriminate methods of

management of waste include burying of waste, burning, open disposal into drains and direct discharge into water bodies. In as much as these methods are not the best practices for solid waste management, they are mostly practiced in Accra regardless of the effects on the environment and water resources (Samwine T., 2017).

## **2.6 Types and Sources of Solid Waste in Ghana**

Waste is generated every day in the society, with varying types such as: municipal, medical, commercial and agricultural waste. All forms of waste ranging from residential to construction are considered as municipal waste (Bello I.A, 2016). Municipal or household waste is usually generated from multiple origins where human activities are prevalent. Studies have confirmed that close to 80% of municipal waste in developing African cities are generated from domestic sources and the remaining percentage varies in amount from commercial sources, specifically streets, markets, industries and institutions (Miezah K., 2015). The volume and source (residential, industrial or agricultural) of waste determines the type of waste management approach that is required. Over 70% of populace of peri- urban centres are not connected to regulated sewage system but practice open defecation and pit latrine systems which implies that the major source of groundwater contamination is sewage leachates (Sorensen J.P.R., 2015). Waste from diverse sources have varying characteristics. The various waste types may have composition made up of metals, leather, food, rubbers, batteries, wood, plastic, organic matter, chemicals, bacteria, textiles, sewage and construction remains. The varying composition of the waste represents possible presence of different chemical and biological content. In event of decomposition and seepage, these waste sources introduce varying contaminants into available groundwater (Miezah K., 2015).

## **2.7 Composition of Wastes (Landfills)**

Landfill is defined as a place where trash is buried to remove it from sight. It is engineered in a way that prevents it from polluting ground water, but the case is different in most African cities as landfills are used without lining. Leaching from landfill occurs as a result of decomposition of rubbish in the presence of enough rainfall passing through waste. Landfill contains pollutants that can be classified into four groups namely; heavy metals, xenobiotic organic compounds (phthalates, benzene, phenols), inorganic macro compounds and dissolved organic matter (Kjeldsen P., 2002). The quality of leachate is derived from the composition of waste. The factors affecting the quality of leachate include, the type and source of waste, climate conditions of landfill,



lining and age of landfill. Leachates with predominate chemical composition are basically made up of municipal solid waste (Moody C.M., 2017). Heavy metals such as fluoride, lead, arsenic and cadmium are constituents of waste deposits in landfills. This constitute hazardous potential to soil and groundwater (Baawain, 2017). The mineral composition of waste consists of sodium, ammonium, potassium, bicarbonates, sulphates, Iron, Zinc, aluminum and other trace elements. Some landfills also harbor biological contaminants and fatty acids such as acetic, propionic and butyric acids. Composition of the waste comprising of minerals settle at the bottom of the landfill and pose danger to groundwater aquifers (Naminata S., 2018).

## **2.8 Leaching into Groundwater**

The extent of groundwater contamination through leachates is dependent on the type of waste at the dumpsite, the management of the site and proximity to aquifer. In the Accra Metropolis, more than 80% of the informal settlements depend on groundwater for domestic use (Charles A.C., 2017). Groundwater quality is explicitly linked to the landcover under which the water is stored. Most cases, the topography is vulnerable to human activities that increase pollution of the reservoir. The pollutants are transferred from the land surface to the unsaturated zone of the underground cover. In the presence of rainfall, water percolates through the layers and enter the water table into groundwater. The prominent source of contamination of aquifers is leaching from un-engineered landfills and dumpsites (Egbi C.D, 2017). Several researches have shown that landfills contaminate groundwater quality and the level of leachate is dependent on the structure of waste. Physiochemical analysis conducted by (Boateng T.K. F. O., 2018) in the Oti .

landfill area of Kumasi Metropolis concluded that leachates from the landfill were highly alkaline with high COD and BOD. Landfill leachates are usually made up of elements such as nitrates and ammonium which are dangerous for consumption (Boateng T.K. F. O., 2018). A study conducted by (Cui, 2017) using the 2.5 years of leaching test showed that electronic waste at dumpsites have the tendency to contaminate porewater. Their results showed increase levels of trace elements such as Cu, Zn, Al were leaching into underground water and soil over the years.

## **2.9 Groundwater Use in Accra (Types)**

Groundwater is a finite source of water supply and provides considerable quantity of potable water for many communities in Ghana. It is the main source of water that should be of concern for government considering the increasing rate of surface water pollution and population growth in

most urban communities in Ghana. In the informal settings of Accra, less attention is given to the quality of water from wells as compared to the quantity. Even though studies and public surveys of the physical condition of groundwater sources in the area showed vulnerability to pollutants (Boateng T.K. F. O., 2018). The quality of water may be compromised by pollutants and cause hydro- chemical and faecal infections. Due to the poor living conditions of inhabitants of slums, wells are constructed within shallow depths and once a well is constructed, quality analysis is not monitored during the time of use (Grönwall, 2016). 400 million people in Sub- Sahara Africa depend on groundwater usage but groundwater resources are highly underutilized despite Zambia having the highest potential followed by Ghana (Association, 2018). The greater percentage (95%) of groundwater use in Ghana is domestic uses except for small -scale farming and commercial purposes. 40.4% of households depend on various sources of groundwater with greater populace in peri- urban centres and rural settings. The categories of groundwater sources in Ghana include hand -dug wells, hand pump wells, boreholes and electric pump boreholes. Wells and boreholes complement water supply problems of Ghana Water Company while serving as a low-cost alternative. For the purposes of industrial utilization of groundwater, bottled water companies depend on it as raw water accounting for 1% of usage. (Frimpong Y., 2018).

## **2.10 Groundwater Quality**

Groundwater is an essential source of water supply, so protection of the quality is as important as its availability. Studies have shown that groundwater in its natural state is relatively clean compared to surface water. Groundwater moves through pores and different types of rocks which make up the mineral content of the water. During the natural breakdown of rocks, minerals are released into the aquifer. The suitability of groundwater for human consumption is dependent on the human activities within the environment of the aquifer (Boateng T.K. F. O., 2016). When rain falls or irrigation water runs through the surface of the ground, dilute chemical constituents infiltrate into the soil. In the case where the landcover is a rubbish dumpsite, rainfall facilitates the washed off waste to infiltrate into the aquifer. This increases the chances of contamination as landfills of uncontrolled dumpsites are susceptible to infiltration of pollutants into groundwater (Nyarko, 2008)

## **2.11 Physiochemical Indices of Groundwater Quality**

Water used for drinking and other domestic purposes have some indicators with safe threshold limits. The prominent chemical indicators of water quality include cations such as calcium,

potassium, magnesium, ammonium, manganese, iron and sodium. The anions comprise of nitrate, nitrite, bicarbonate, hydro- carbonate, phosphate, chloride and sulphate. Depending on the geology of the groundwater aquifer, some major elements and heavy metals can also be found which includes: fluoride, lead, mercury, zinc, aluminum and arsenic (Nyarko, 2008). These physical and chemical indicators make up the mineral content of the water and its suitability for human consumption. In determining the acid and basic concentration of water, pH is used, which represents the algorithm of the hydrogen ion concentration. The concentration of ions in the water is dependent on the electrical conductivity of the water and relatedness to extreme hardness (Labh, 2017). Turbidity is measure of the ability with which water loses its transparency to suspended particulates. It is considered as a good degree of physical water quality and provides an estimation for total suspended solids (TSS) (LENNTECH, 2019). A heavy metal such as fluoride is good for dental health, but extreme exposure is paramount to cavity decay. On the average, the chemical contaminations from water quality indicators take years to manifest but the case is different for nitrogen compounds. A baby fed with water containing nitrogen experiences “blue baby syndrome” within couple of days. The same applies to ulcer and dialysis patients (Galan, 2018). In as much as Nitrogen is abundant in the atmosphere (78%), exposure to groundwater is mainly by infiltration due to fertilizer applications, animal feed and runoff into open wells. Nitrogen in its oxidation state in water gives rise to compounds such as nitrite, nitrate and ammonium which play an essential role in the quality indices of groundwater (Perlman, 2017). Low traces of arsenic in groundwater poses health consequences of cancer and eventually death. The chemical occurs naturally in water as part of sedimentation of rocks but activated through anthropogenic activities such as mining, industrial remains and animal feed. Studies conducted in United States confirmed wells in twenty-five (25) States are contaminated with arsenic and 100million people exposed to arsenic poisoning in Bangladesh (USGS, n.d.). Chlorine (Halogen) is naturally existing in rocks and can be found as a constituent of sodium, potassium and calcium in the form of salt. The concentration can be increased through leaching through landfills, salt intrusion from coastal aquifers and release from sewage treatment plants. Increase consumption of high levels of chlorine can result in heart problems and high blood pressure. Other elements such as magnesium, calcium and phosphate contribute to the hardness of water which limits the usability of the water for domestic purposes (Adugnaw T. Akale, 2017). Although mercury occurs naturally in rocks, recent studies indicates increase of the element in groundwater is due to massive human activities such as improper disposal of industrial waste, municipal solid waste incineration and direct discharge of

medical waste into the environment (González-Fernández B., 2014). Wells and boreholes in the vicinity of landfills can expose water to heavy metals such as lead through contaminant seepage. The effect on the human body is dependent on exposure time (Negi P, 2018). The various physiochemical indicators of groundwater quality have permissible values within the guidelines of the World Health Organization (WHO).

## **2.12 Biological Indicators of Groundwater Quality**

Diseases associated with contamination of groundwater is profound in overcrowded African cities. This results in outbreak of water related infections such as cholera, diarrheal and dysentery. Pollution of groundwater with causative agents (*E. coli*, Faecal Coliform and Total Coliform) of such diseases include direct discharge of sewage water in un-engineered landfills, leakage from septic tanks and sewage. Biological contaminations also emanate from animal excreta in open landfills (Osvalda De Giglio, 2017). Faecal and total coliform is the basic indicator for biological suitability of water for drinking. It measures the presence of disease-causing bacteria in water. The presence of *E. coli* in water is an indication of infection by faecal matter or faeces from animals. Shallow and open wells are most susceptible to faecal matter contamination. In the case of high colonies of coliform found in water, the implication is the presence of bacteria such as *Giardia* and *Cryptosporidium* and other viruses and protozoa. The test for faecal coliform can be done by membrane filtration to retain the bacteria within 6 to 24 hours after sampling (Oram, 2014).

## **2.13 Ghana Water Policy**

The Ghana national water policy highlights the provision of quality water and sanitation in the focus area twelve (12) of the National Water Policy. One of the core quality focus areas is the prevention of pollution of water resources in the environment. The central objectives of the policy comprise of; prevention of indiscriminate discharge of solid or municipal waste into the environment and sustainable management of municipal sewage system for all. This is intended to promote proper management of sewage in the various cities (NWP, 2007). In terms of institutional support, Ghana Water Company Limited (GWCL) is to coordinate the provision of quality drinking in terms of rural and urban water supply but this takes effect only in planned settlements of the city of Accra. The slum communities depend on dug wells with no quality assurance because the GNWP of 2007 barely captures the reality of the situation. The National Drinking Water Quality

Management Framework for Ghana (NDWMFG) indicates the need to address the quality of water used on a holistic approach with decentralized case specificities both in urban and peri- urban centres (NDWQMFG, 2015). There is therefore the need to determine the quality of groundwater use in the slum suburbs of Accra in order to ascertain the permissibility for human consumption and develop a case specific policy framework to fill in the gaps within the national water policy.

## **CHAPTER THREE**

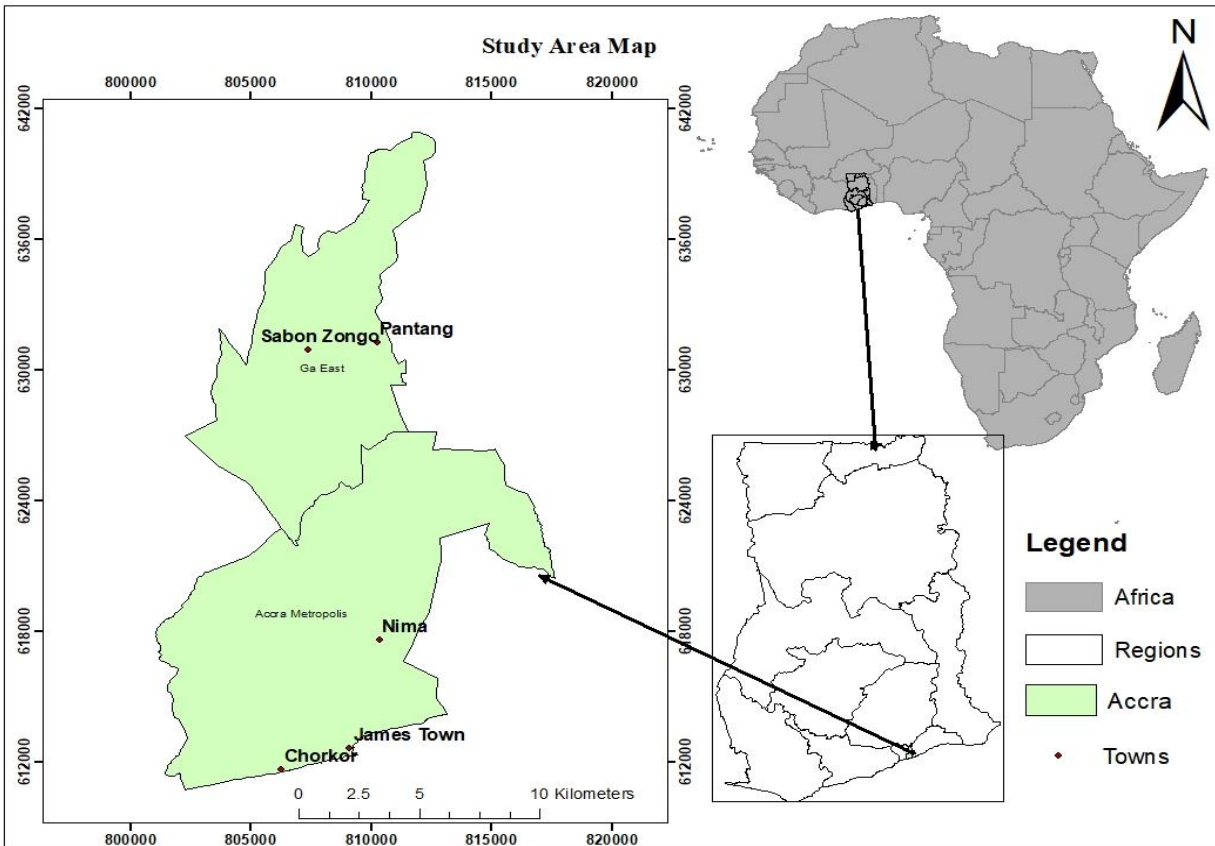
### **3.0 MATERIALS AND METHODS**

#### **3.1 Study Design**

The study incorporated mixed- method research design. The purpose of this methodology was to obtain basic information from surveyed water users to aid in policy brief formulation and at same time also conduct groundwater study. ArcGIS and STATISTIX statistical packages were used to analyze and represent data in form of tables, graphs and maps.

#### **3.2 Study area- Accra**

Accra is the capital city and the most populated city of Ghana. It constitutes a population of over 4 million inhabitants making it the 11<sup>th</sup> biggest city in Africa (Review, 2019). Greater Accra region is the smallest region in terms of land coverage (3245 square kilometers) but is highest in occupants. The city shares boundary in the east by Volta region, north by the Eastern region, west by the Central Region with the Gulf of Guinea in the south. Accra lies at latitude 5.6037 decimal degrees north and longitude 0.1870 degrees west with an elevation of 61m above sea level. The city lies within the coastal savannah agroecological zone of Ghana. The geology of Accra is mainly of the Togo and Dohomeyan thrust rock formations with frequent tremors in recent time (Nyarku M, 2011). For the purpose of the study in the city of Accra, five (5) major slums (Nima, Sabon Zongo, Chorkor, Jamestown, Pantang-Abokobi) have been selected within the city for water sample collection. Below is the detailed information about the specific areas;



**Figure 3.1: A map showing the study area-Accra**

(source: Author's creation)

### 3.1.1 Accra- Nima

Nima is the biggest slum in Accra. The community has a population of about 55,830 inhabitants. The slum is located at latitude 5.5820 and longitude 0.1984 decimal degrees. The community shares common facilities such as toilet and water. Most of the houses do not have their own toilets but share a central public toilet. Waste disposal is done by direct discharge in drains or central dustbins. The indigenes live in clustered houses with poor sanitation conditions. Some parts of the slum are connected to municipal pipe water but the less endowed still depend on hand- dug wells for domestic purposes.



**Figure 3.2: Nima Slum**

*Source: (Eunice Yorgri, 2017)*

### **3.1.2 Accra- Sabon Zongo**

Sabon Zongo is a slum community located in the Ablekuma- Central Municipality of Accra. The area lies at latitude 5.5551 °N and longitude 0.2374 ° W. Waste management in the community is generally poor (Owusu, 2010). Indigenes dispose of waste in gutters and share public pit latrines within the same environment as the as Boreholes and hand-dug wells.



**Figure 3 .3: Showing a hand-dug well situated behind a pit latrine (Image from researcher's field work 2019)**



### 3.1.3 Accra- Chorkor

Chorkor is a heavily populated fishing slum in the Metropolis of Accra. The slum is situated on the eastern Atlantic coast of the capital city. It lies at an elevation of 12m above sea level. The houses within the community are closely packed and solid waste disposal is done in the shores of the sea. Households share a common toilet facility. Individual households in Chorkor do not have their own water sources but share a central municipal water and private boreholes. The boreholes are mostly situated in the premises of the public toilet (Acheampong, 2016)



**Figure 3.4: Chorkor slum in Accra**

*Source: (Smith-Asante, 2015)*

### 3.1.4 Accra -James town

Jamestown is one of the oldest communities in Accra. It has been built since the 17<sup>th</sup> century but the community has become a slum over the years in light of urbanization. The community inhabit historic forts and monuments for tourist attraction. The inhabitants are mainly fishermen. Waste management is by truck collection. The populace uses municipal water but some households depend on wells built during the colonial era. The community lies at 37.2116 degrees north and 76.7752 decimal degrees west.



**Figure 3.5: Map of Jamestown**

### 3.1.5 Accra- Pantang-Abokobi

Pantang- Abokobi community is a place situated around the oldest dumpsite in the Ga East municipality of Accra. The landfill area covers about two (2) acres of land. The un- engineered landfill started from the 1990s until it was closed in the year 2014. The area surrounding the dumpsite has become a resident community for city dwellers. The area is not covered by municipal water but treated water is sold in tankers. In the absence of connected pipes, the residents of the area have drilled boreholes for domestic uses regardless of the dumpsite. The developing community lies at 5.44 decimal degrees north and 0.12 decimal degrees West at an elevation of 74m above sea level.



**Figure 3.6: Pantang- Abokobi dumpsite community**

*Source: EPA 2014*

### **3.2 Climate of Accra**

The general weather features of Ghana are tropical, warm and dry along the coastal zones. The average temperature of Accra is 30° with a maximum of 34° and minimum of 24°. Rainfall variations are significant and characterized by bimodal rainfall features. The first wet season is May to July and second is September to November. The wet months range between May to July with maximum amount of rainfall in May to June. June represents the maximum rainfall peak accompanied with average rainfall of 143.9mm. The driest month of the year is January with average rainfall of 7.7mm. The average annual precipitation of Accra is 810mm (GMET, 2016). The average relative humidity of the city is 83.0%. Geographical terrain of Accra is mainly flat with few hilly areas.

### **3.3 Hydrogeology of Accra**

The rock formation and geology of Accra is mainly the Dahomenyan rock formations. The Dahomenyan rocks consist of two types which includes the meta basics and basic intrusive (Nonterah, 2019). The geology of Accra bears the two categories of rocks. Studies conducted shows multiple fractured areas of bed rock formation. This indication provides a viable implication that the region is good for borehole drilling and groundwater extraction. (ERDÉLYI, 2010).

### **3.4 Data Acquisition/ Sampling**

Groundwater samples were collected from five (5) slums in the city of Accra. The samples were collected in five (5) batches, four from each community thereby making a total of twenty samples. The groundwater sources were sampled based on which source the community uses. Majority of the communities have more hand-dug wells than boreholes.

#### **3.4.1 Criteria for borehole/ well selection**

The boreholes were selected randomly in the slum communities. Snowballing sampling technique was used to sample the water. This means moving from household to household until the required number of samples needed per community is attained. Depending on availability, the groundwater source is either borehole with a tap or hand-dug well. In a community, an estimated 100 meters was kept between sampling locations of sampled groundwater sources.

### **3.5 Procedure**

The procedure for sampling is different depending on the type of analysis. Fluoroplastic bottles were used to sample water for physiochemical analysis while sterilized glass bottles were used for bacteriological samples.

#### **3.5.1 Physiochemical Water Sampling**

Fluoroplastic bottles of 1500ml were thoroughly rinsed with distilled water prior to sampling and kept in a cooler. Upon reaching the site of sampling, the water was collected directly from the ground water source. The tap was allowed to flow for about two minutes at maximum flow and the water was then used to rinse the bottle twice before sampling.

#### **3.5.2 Bacteriological Water Sampling**

The glass bottles were sterilized in the laboratory prior to sampling. In the process of sterilization of the bottles, two drops of sodium thiosulphate were added in the bottle after its been rinsed with distilled water. The sodium thiosulphate was used to neutralize any chlorine that might be present in the water or bottle. Thereafter, the bottles were corked and wrapped in aluminum foil and placed in the autoclave for two hours at the temperature of 200 °C. The bottles were kept in the oven until ready to use.

Upon reaching the field, the tap of the groundwater source was thoroughly cleaned and wiped with a clean cloth to remove any visible dirt and external materials. The tap was then sterilized using alcohol-soaked cotton and a burning flame. The tap was opened to flow at the maximum speed for two minutes and medium speed for one minute. The lid of the wrapped glass bottle was carefully opened and glass bottle placed under the tap with the cork facing downwards and the water sampled and immediately closed. The samples were placed in an ice filled cooler at approximate 4 ° and transported to the Accra East Central Laboratory of Ghana Water Company Limited. The duration of sampling and transportation to the laboratory was done in less than six hours.

#### **3.5.3 Hand-dug well sampling**

Open wells were also sampled but with a different procedure compared to the borehole taps. The bacteriological samples were conducted with a clean and alcohol sterilized string attached to the glass bottle and lowered in the well until it was totally immersed. The bottle containing the water

was gently pulled out without touching the walls of the well and immediately corked and placed in an ice cooler. The sampling technique for physiochemical is the same as biological except that, a clean rock was attached to the bottle in other to facilitate immersion of the bottle and the water was sampled into a plastic bottle.

### **3.6 Laboratory analysis**

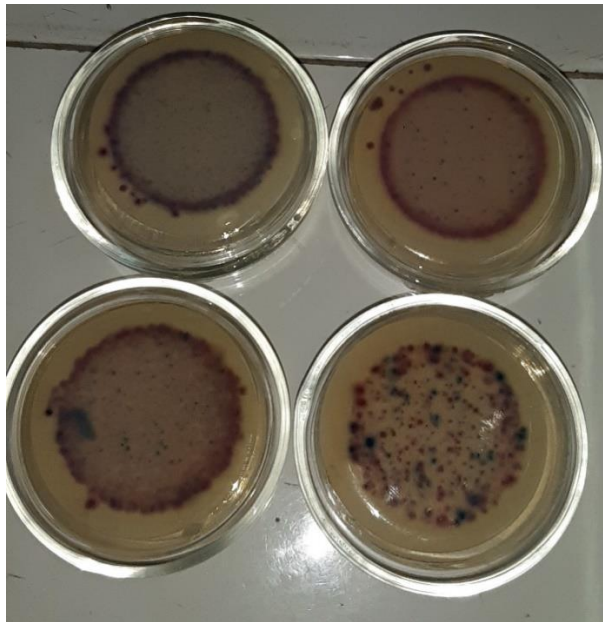
The physiochemical and bacteriological analysis were carried out by a team of laboratory experts at the central laboratory of the Ghana Water Company Limited, Accra, Ghana. The biological analysis was conducted the same day that the samples were collected.

#### **3.6.1 Microbial Analysis**

The membrane filtration technology was used to determine the *E. coli* amounts and total coliforms in the samples. In other to facilitate formation of colonies of coliform in the water, a media was prepared. The media used is *Coliform Agar Iso 9308-1*. In preparation of the media, 26.5g of the coliform Agar was dissolved in 1 litre of distilled water (Rodger B. Baird, 2017). The mixture was stirred gently and placed on a hot plate till it started to boil. The media was cooled to about 45 to 50 degrees. A considerable amount of the prepared media was poured in required number of sterilized petri dishes and allowed to solidify. The plate was covered as the filtration process was initiated. The water samples were removed from the ice cooler and placed on a sterilized laboratory counter. The UV- sterilizer was pre-heated for about fifteen minutes and the manifolds were also sterilized in the autoclave at 121 degrees. The two manifolds were placed on the filtration stand and the burning flame was ignited. The membrane filters were carefully opened and placed on the manifolds with an alcohol and flame sterilized forceps. The manifold funnel was placed on the stand bearing the filter and 100ml of the water sample was poured in it. After the filtration process was completed, sterilized distilled water was used to cleanse the funnel to remove any excess sample. The filter was carefully removed and placed on the prepared media and incubated at 37 degrees for 24hours. In between different sample filtrations, the manifolds were sterilized in the UV-sterilizer for 5 minutes in other to prevent cross contamination in between the different samples. The results were recorded after 24hours of incubation. *E. coli* was used as the indicator organism for the presence of bacteria and were identified as green colonies and total coliform bacteria identified as purple colonies.



**Figure 3.7: Membrane filtration setup (Laboratory work 2019)**



**Figure 3.8: Coliform bacteria formed after 24-hour incubation (Laboratory work 2019)**

### **3.6.2 Physiochemical analysis**

The analysis conducted on the samples include; temperature, pH, turbidity and electrical conductivity. Other parameters were also determined using titration methods. These includes total alkalinity, total hardness, calcium hardness, magnesium hardness and chlorine contents. The rest of the parameters were measured using the spectrophotometer.

## **Temperature**

The temperature of the samples was measured with the use of a thermometer. A considerable amount of the water sample was transferred into a beaker and the thermometer was inserted. The results were recorded in degrees Celsius. The temperatures recorded were the temperatures at which the analysis was carried out.

## **Turbidity**

The turbidity of the water samples was measured using *Iso Turbidimeter HI 98713*. The accuracy of the device was tested with samples with known values of turbidity. The groundwater samples were transferred into the transparent bottle and the measurement was recorded in FNU and later converted to NTU.

## **pH**

The hydrogen ion concentration of the water was determined with the aid of a pH meter. The device was immersed in a beaker containing the water sample. The pH value was then recorded. The same procedure was repeated for the rest of the samples.

## **Measurement with spectrophotometer.**

### **Fluoride**

The fluoride content of the sample was determined using the SPADNS method in spectrophotometry. The Hach program was set to 190 Fluoride. The device was set to a 2-minute reaction window. Thereafter, 10ml of the sample was pipetted into the sample cell and 2.0ml of the SPADNS reagent was added to the sample cell and swirled carefully. The cell was placed in the cell chamber and results read at 580nm (Hach, 2004).

### **Iron**

The FerroVer method was used to measure the iron content in the water sample. The FerroVer Iron reagent was added to 10ml of sample in the sample cell bottle. The Hach program was set 265Iron Ferro Ver and three-minute reaction period was allowed. The cell was then placed in the cell chamber. The ferrous iron reacted with the phenolphthalein indicator to form an orange colour, which is proportional to the level of iron in the sample. The results were read 510nm. (Hach, 2004).

## **Manganese**

Manganese was measured in the sample using the spectrophotometer under the influence of ascorbic acid as reagent using the 1-(2-pyridylazo)-2-Naphthol PAN method. The method is a sensitive method which enables the detection of low levels of manganese in water samples. The ascorbic acid powder pillow reagent was used in 10ml of water sample. The cap was inverted gently to attain a uniform mixture and the Hach program was set to 90 Manganese LR and the results were read at 560nm (Hach, 2004).

## **Potassium**

Potassium in the groundwater sample was measured using the tetraphenylborate method. 20ml of the sample was pipetted into the sample cell and potassium reagent powder pillow 1, 2, and 3 were added. The mixture was inverted several times for uniformity. The blank cell was placed in the chamber and zeroed. A seven-minute reaction time was allowed. The cell was placed in the chamber and the Hach program was set to Potassium 905 and results read at 650nm (Hach, 2004).

## **Sulphate**

SulfaVer 4 method was used to determine the sulphate amount in the collected samples. 10ml of the sample was transferred into a cell bottle and SulfaVer 4 reagent was added. The bottle was swirled multiple times to attain uniform mixture. Thereafter, the Hach program was set to 680 Sulfate and 5-minute reaction time was allowed. The barium in the reagent reacted to form a precipitate sulfate. The amount of turbidity was proportional to the sulphate concentration in the water sample. The final test results were read at 450nm (Hach, 2004).

## **Nitrate**

The Nitrate component of the samples were measured spectrophotometrically using the Cadmium reduction method. 10ml of the sample was pipetted into a cell bottle and nitrate reagent powder pillows were added. The mixture was inverted to mix. The Hach program was set to 355N, Nitrate HR. A one-minute reaction period was allowed and thereafter the cell was placed in the cell chamber after the timer beeped. The Cadmium metal in the reagent reduced the nitrate ions in the sample to nitrite (Hach, 2004). The outcome was recorded at 430nm. The results were later multiplied by a factor of 4.4 to obtain the nitrate value.



### **Total Suspended Solids**

The total suspended solids in the sample was directly measured using the Spectrophotometer. 20ml of the sample was used and placed directly in the chamber cell without any reagents. The Hach program was set to 630 suspended solids (Hach, 2004). The photometric method was used and the results were read at 810nm.

### **Gravimetric Methods/ titration**

The constituents that were measured using this method include; total alkalinity, total hardness, calcium hardness, magnesium hardness, chloride concentrations and nitrite. Prior to the procedure, standardized solutions were prepared.

### **Total Alkalinity**

The total alkalinity of the sample was determined using the method of titration. The indicator used was Bromocresol green. Three (3) drops of the indicator was added to 50ml of the sample in a conical flask. The alkalinity test was conducted with 0.02N of H<sub>2</sub>SO<sub>4</sub> as titrant and the volume at which the mixture in the flask turns yellow was recorded. The total alkalinity was later calculated using the formula.

$$\text{Total Alkalinity} = \frac{\text{Titrant value} * n * 50000}{\text{volume of sample used}} \quad \text{Equation (1)}$$

Where n is the normality of the acid used (Na<sub>2</sub>CO<sub>3</sub>) (Rodger B. Baird, 2017). The calculations were computed for the different samples using the respective variables and the result recorded.

### **Total hardness**

The process of titration was used to determine the total hardness in the sample. Ammonia buffer served as the hardness test. 10ml of sample was transferred into a conical flask. Ammonia buffer and few drops of murexide indicator were added. Thereafter, 1ml of 1.0N of NaOH was added as a digester. 0.01M of ETA was used as a titrant and the volume at which the mixture changes colour to c-blue was recorded (Rodger B. Baird, 2017). The same procedure was repeated for the rest of the samples.

The total hardness was then calculated using the formula stated below:

$$= \frac{\text{Titrant value} \times 1000}{\text{volume of sample used}} \quad \text{Equation (2)}$$

### Calcium Hardness

The procedure for calcium hardness is the same as total hardness except the readings were taken at the volume at which the colour changed to purple (Rodger B. Baird, 2017). The same procedure was repeated for the rest of the samples and the respective titrant values recorded. The actual calcium hardness was computed using the formula below:

$$\text{Calcium hardness} = \frac{\text{Titrant value} \times 1000}{\text{volume of sample used}} \quad \text{Equation (3)}$$

### Magnesium Hardness

The magnesium hardness for the samples were derived after the total and the calcium hardness values were determined. The relationship between the variables was used to determine the magnesium hardness.

$$\text{Total hardness} = \text{Calcium hardness} + \text{Magnesium hardness} \quad \text{Equation (4)}$$

Therefore,

$$\text{Magnesium hardness} = \text{Total hardness} - \text{Calcium hardness} \quad \text{Equation (5)}$$

The computations were carried out for the 20 different samples and the results recorded.

### Calcium

The calcium content was also calculated from the results of calcium hardness.

The expression below was used to determine the  $\text{Ca}^{2+}$  in all of the samples.

$$\text{Calcium (Ca}^{2+}\text{)} = 0.4 * \text{Calcium hardness (Rodger B. Baird, 2017)} \quad \text{Equation (6)}$$

### Magnesium

The magnesium cation in the sample was also determined from the results of the magnesium hardness

The expression below was used to determine the  $\text{Mg}^{2+}$  in all of the samples.

Magnesium ( $\text{Mg}^{2+}$ ) =  $0.243 \times$  magnesium hardness (Rodger B. Baird, 2017). *Equation (7)*

### Chloride

In order to determine the chloride level in the water samples, 10ml of the sample was mixed with 65ml of distilled water. The Chlorine test acid used in the process is silver nitrate ( $0.0141 \text{ AgNO}_3$ ). Potassium dichromate ( $\text{K}_2\text{CrO}_4$ ) was used as both indicator and digester. Few drops of the indicator were put in the sample and titrated against the acid until a color change to golden yellow (Rodger B. Baird, 2017). The specific chloride levels in each sample was then calculated using the titrant value and the normality of the acid used ( $0.0141 \text{ AgNO}_3$ ). The volume of the blank titration of the silver nitrate was recorded.

The expression used is stated as follows:

$$\text{Cl}^- = \frac{(A-B) \times N \times 35.45}{\text{volume of sample used}} \quad (\text{Rodger B. Baird, 2017}) \quad \text{Equation (8)}$$

Where,

A= volume of titrant

B= Volume of titrant blank

N= Normality of silver nitrate.

The computations were carried for the various samples and the chloride amounts recorded.

### Nitrite

The reduced nitrogen content of the water samples was determined using the calorimetric method (Rodger B. Baird, 2017). 50ml of the sample was transferred into a conical flask. Thereafter, 1ml of reagent 1 – *Islloveys* and 2ml of *Islloveys* reagent 2 were added. The sample was swirled for consistency and then allowed to react for 15mins. After the reaction period, the sample was transferred into the

shell of the colour compactor and the nitrite discs was inserted. The results were read at the disc calibration at which both colours match. In the case of samples collected from Pantang, the nitrite levels exceeded the reading limit of the disc, so 5- 10ml of the mixture was transferred into a conical flask and diluted with 50ml of distilled water and the process carried out.

The results of the method were later used to calculate the actual nitrite using the formula below.

$$\text{Nitrite} = \frac{\text{Disc reading}^{0.5 \times 3.284}}{\text{sample volume}} \quad (\text{Rodger B. Baird, 2017}) \quad \text{Equation (9)}$$

### Arsenic

Arsenic was measured in the water sample using *EZ Arsenic test kit 2822800* (Hach, 2004). The test kit bottle was opened and the test strip was inserted downwards. The bottle was filled to the mark with the sample and reagent number 1 and 2 were added. Right after that, the cap was attached and the bottle swirled gently for one minute without sample coming in contact with the strip. A waiting period of 20 minutes was allowed, with 60 seconds swirling at the 10<sup>th</sup> minute. Thereafter the color indication on the strip was matched to the attached color code in the kit and corresponding results were recorded.

### Lead

The amount of lead in the samples were measured using the Fast Column Extraction method combine with the use of spectrophotometer. The Hach program was set to 283 Lead, Lead track LR. Thereafter, 100ml of the sample was transferred from a graduated cylinder into a beaker. With the help of a dropper, 1ml of Pb-1 acid preservative was added to the sample and mixed accordingly. After acid preservation of sample, a two-minute reaction time was allowed on the spectrophotometer. After the reaction period ends, 1ml of Pb-2 was added and swirled. A new fast extractor was mounted on the clamp and a 150ml beaker was placed under the extractor. Different extractors were used for all of the samples. Distilled water was added to the cotton in the extractor and the compressed by the plunger until it moved up and a clean rod was used to push it back to the mark. The sample was slowly poured into the column extractor with a slow flow rate of 2 drops per second down the extractor. After the flow ended, the plunger was used to compress the cotton pad until no drop came out. The plugger was removed from the extractor and the content of the beaker was discarded. A clean 25ml sample cell was placed under the extractor and 25ml of Pb-3 effluent solution was added just above the cotton pad. Thereafter, the effluent was allowed to drip slowly from the extractor. After the flow stopped, the absorbent was compressed until the last drop and the 25ml mark on the cell was reached. Pb-neutralizer was added to the solution in the cell and mixed properly. Pb-5 was added to the mixture and swirled for uniform mixture. The time was started on the spectrometer and a two-minute reaction window was allowed and the sample cell was placed into the chamber after the timer beeped. The Zero icon was touched and it read 0ugL.

After that, the cell was removed and six drops of Pb- 6 decolorizer was added and swirled for thorough mixture. The sample cell was placed inside the chamber and results of lead content was read at 477nm (Hach, 2004). The same procedure was repeated for all the samples.

### **Zinc**

The Zinc level in the water sample was measured using the spectrophotometer under the Zincon method. 20ml of the sample was transferred into the cell bottle and divided into 10ml bottles each. *Zincover* pillow was added to each of the 10ml and set aside. One of the 10ml sample was used as blank and 0.5ml of cyclohexanone was added to the other 10ml. The Hach program was set to 780 Zinc. And timer of 30seconds was set for vigorous shaking of the mixture. The spectrophotometer was set to reaction period of 3 minutes and the blank was used to zero the program before inserting the sample to be read. The results were read at 620nm (Hach, 2004).

### **Phosphate**

Phosphate in the sample was determined using the *PhosVer 3* Method (Hach, 2004). 10ml of the sample was transferred into the cell and another 10ml set aside as blank. The Hach program was set to *490 P React. PV*. The timer on the spectrophotometer was set to 2 minutes reaction period and the blank was placed in the cell chamber after timer beeped. Thereafter, all of the content of *PhosVer 3* powder pillow was added to the 10ml sample and inverted to mix. Another two minutes reaction time was set and the mixture was shaken vigorously to dissolve all powder pillows. The cell was placed in the chamber and the results read 880nm (Hach, 2004).

### **Electrical conductivity**

The Electrical Conductivity was measured directly using the device, *Hach Hq40d*. A considerable amount of the sample was poured in a beaker and the device was inserted and the conductivity value was recorded (Hach, 2004). The same procedure was repeated for all the samples.

### **Total Dissolved Solids**

Total dissolved solids were determined using calculation method

$$\text{TDS} = \text{Electrical conductivity} * 5 \text{ (Rodger B. Baird, 2017)}$$

*Equation (10)*

The calculation was carried out for all the twenty samples.

### **3.7 Field survey (Questionnaire Administration)**

In order to acquire basic information about the groundwater usage in the slums, a simple questionnaire was administered. The questionnaire was rendered to the owners of the household and in most cases the major users of the water. The questions addressed the major uses of the water and proximity to landfills or pit latrines in order to anticipate possible contamination. Verbal interviews and researcher's observation were also taken into consideration.

#### **3.7.1 Data collection ethics**

The information collected from the water users in the community was given out of free will after thorough explanation of the purpose of the exercise. The community members were not coerced into participating in the exercise and the indigenes were made to understand they could opt out the exercise when they so choose. There were cases where household owners did not give consent for water sampling or questionnaire administration and those households were excluded from the exercise. No personal information concerning the households were collected. Also, no compensations were given in exchange for information.

### **3.8 Data Analysis/ Processing**

The result obtained from the laboratory was entered into Microsoft excel. Simple statistical calculations such mean, median and mode were computed. The data table was then imported to STATISTIX version 10 for other analysis to be conducted. After the data was imported to the software, descriptive statistics were carried out. The characteristics include mean, median, standard deviation, variance, C.V, minimum, maximum, skewness and kurtosis. The descriptive table for all the water quality parameters was saved in the text format. Histograms were plotted using the 'summary plot' command in the STATISTIX software. The histograms were then normalized using the 'categorical model' and 'display normal curve' commands. The same procedure was repeated for all the 27 water quality parameters and the histograms saved in jpg file extension format. The normality of the histograms was checked and the non-normal histograms were transformed in Microsoft excel by calculating the log of the parameter value. The transformed data was imported into STATISTIX software and the histograms recreated. In order to conduct the Analysis of Variance (ANOVA) for the data, the data was imported to excel and 'Analysis of variance' was selected 'under 'Statistics' command after which 'Completely Randomized AOV' feature was

selected. All the parameters were uploaded and name of the slums in the excel data was used as the 'treatment variable'. Completely Randomized AOV values for all the parameters was transferred to the ANOVA table. After the ANOVA was executed, the mean separation of the parameters was also carried with Multiple Pairwise comparison under the 'LSD' comparison method. The mean of slums of effective cell size was saved from the ANOVA analysis. The mean values from ANOVA is what is compared to the standard WHO guideline of each water quality parameter. A comparison table between the mean of water quality parameters per slum and the standard WHO guideline was created in Microsoft word.

### **3.8.1 Geospatial Analyst Extension mapping in GIS**

The coordinates of the well locations were downloaded from the GPS device using *DNRGPS* application. The coordinates were saved in Microsoft excel file with *csv* file extension. The *csv* data was then added in ArcGIS version 10.4. and shapefile created. The Geostatistical Analyst Extension tool was used to create the map using the coordinates. The concentrations of water quality parameters were also mapped per the distribution in each slum community.

### **3.8.2 GS+ creation of Variograms**

The excel file containing the coordinates and the quality parameters was imported to GS+. A water quality parameter was selected and the variogram created using the software. The procedure was repeated for all water quality parameters under the study. Thereafter the respective model (Gaussian, exponential and spherical) table was created from the outcome of the variogram.

## **3.9 Groundwater Policy Brief Creation**

A comparison review of National Drinking Water Quality Management Framework for Ghana (NDWQMF) 2015, National Water Policy (NWP) of 2011 and Groundwater Management Strategy of (GMS) of 2011. The three documents were reviewed to compare the highlights of groundwater quality and pollution preventive measures. The sectors responsible for quality assurance and resource protection were also used as a criterion for effective policy framework suitability. A policy brief and an institutional framework was created to fill in the gaps in the three (3) policy documents reviewed.

## CHAPTER FOUR

### 4.0 RESULTS AND DISCUSSION

#### 4.1 Summary of descriptive statistics for water quality parameters in 5 slums in Accra

The summary of descriptive statistics for water quality parameters in 5 slums in Accra is presented in Tables 1 and 2. Table 1 shows the statistical summary of all physical parameters, major salts and fluoride. The summary shows that pH has a mean distribution of 6.26 and relatively minimal variance of 0.96 which implies that the data points are not spread out from the average point. The closeness of the mean to the median and mode indicates normality of the data even though it is negatively skewed to the right. The peak of the pH data is flat with kurtosis less than 3. The temperature values in the dataset is the temperature at which analysis was carried out. Room temperatures used shows a mean of 25.06 °C with the same values of mode and median. There is a high disparity between the statistical parameters of turbidity values. The mean of 1.64 is less than the median of 1.11 which is also relatively far less than the mode of 0.66. The high disparity between the points is attributed the high standard deviation greater than 1.0. The kurtosis of 14.7 which is greater than 3 implies non- normality of data points. The variance of EC data points is significant with standard deviation of 189.75. The minimum value is 24.50 with a maximum of 827.50. This is an indication of a wide spread of points as mean, mode and median values also shows a vast range with no closeness. Kurtosis of 4.63 is an indication of a non- normal data. All salt producing parameters such as calcium, magnesium, chloride, sodium, bicarbonates, total hardness and TDS showed varied degrees of disparity. The standard deviation in these parameters ranged between 67.42 to 627.07. This indicates that all the salt parameters are spread out away from their mean values. There is no relative closeness between the mean, median and the mode of the salt parameters measured. The wide spread of the data values suggests non- normality even though the kurtosis of all the salt constituents are greater than 3 except for magnesium and total hardness. The data points also show positive skewness values ranging from 1.45 to 2.22. The coefficient of variance (CV) in the data also shows great extent of variability in the mean values. Total alkalinity also exhibited some degree of deviation from the mean values with a minimum value of 6.0 and maximum of 342. There is a relatively high difference between the mean and median. Kurtosis of 2.77 could suggest normality but the degree of variance in other descriptive parameters implies non- normality. The last parameter in Table 1 is fluoride. The mean value of 0.39 is relatively close to the median of 0.41 with a minimal standard deviation of 0.25. The



minimum fluoride value is 0 and maximum is 0.86. The fluoride data has negative skewness and a negative Kurtosis less than 3. This implies normality of fluoride concentrations in the slums.

*Table 4.1: Summary of descriptive characteristics of water quality parameters in 5 slums in Accra*

**Table 1**

<b>Parameters</b>	<b>Mean</b>	<b>SD</b>	<b>Variance</b>	<b>CV</b>	<b>MIN</b>	<b>MED</b>	<b>MAX</b>	<b>SKEW</b>	<b>KURT</b>	<b>MODE</b>
<b>pH</b>	6.26	0.98	0.96	15.67	3.77	6.44	6.44	-1.09	0.61	6.44
<b>Temp</b>	25.59	1.32	1.32	5.16	24.00	25.00	29.00	1.46	1.61	25.00
<b>Turbidity</b>	1.64	2.27	5.14	138.08	0.29	1.11	11.50	3.82	14.07	0.66
<b>EC</b>	172.94	189.75	36007	109.72	24.50	92.80	827.80	2.22	4.63	120.80
<b>TDS</b>	693.99	627.07	393216	90.36	122.50	455.00	2756.5	1.92	3.35	604.00
<b>Hardness</b>	351.46	234.85	55152	66.82	100.00	270.00	1010.0	1.45	1.27	290
<b>Ca</b>	84.69	67.42	4544.9	79.598	20.000	68.000	340.00	2.47	7.02	32
<b>Mg<sup>2+</sup></b>	133.41	110.10	12123	82.53	20.000	100.00	440.00	1.6632	2.2610	14.58
<b>Cl<sup>-</sup></b>	492.91	542.11	293878	109.98	69.98	264.92	2364.3	2.22	4.64	344.89
<b>HCO<sup>3-</sup></b>	103.20	94.67	8961.4	91.73	7.32	77.47	417.24	1.85	3.63	
<b>Na</b>	319.90	351.82	123780	109.98	45.410	171.93	1534.4	2.22	4.64	223.83
<b>T Alkalinity</b>	92.43	78.19	6115.0	84.60	6.00	72.000	342.00	1.60	2.77	
<b>F</b>	0.39	0.25	0.06	64.82	0.00	0.41	0.86	-0.05	-0.92	0

Table 4.2: Summary of descriptive characteristics of water quality parameters in 5 slums in Accra (Table 4.1 continued)

**Table 2**

Parameters	Mean	SD	Variance	CV	MIN	MED	MAX	SKEW	KURT	MODE
<b>K</b>	35.82	22.24	494.6	62.08	5.7	32.5	77.2	0.27	-1.18	
<b>Fe</b>	0.05	0.05	3.43	110.39	0	0.04	0.24	1.98	3.54	0.03
<b>S</b>	73.92	22.75	517.53	30.77	19	79.5	115	-0.63	-0.05	93
<b>Mn</b>	0.2	0.36	0.14	180.48	0	0.068	1.37	2.56	5.1	
<b>NO<sup>3-</sup></b>	51.78	28.51	812.86	55.06	7.04	52.91	114.84	0.38	-0.34	
<b>NO<sup>2-</sup></b>	0.04	0.07	4.46	178.18	0	6.58	0.23	0.23	3.76	0
<b>Pb</b>	0.55	0.72	0.52	131.73	0	0	2	0.94	-0.41	0
<b>NH<sup>4+</sup></b>	0.58	0.86	0.73	148.1	0	0.39	3.87	2.86	8.01	0
<b>PO<sup>4</sup><sup>3-</sup></b>	0.41	0.56	0.32	136.8	0.05	0.17	2.11	1.94	2.58	0.12
<b>As</b>	0	0	0	0	0	0	0	0		0 0
<b>Zn</b>	0.11	0.21	0.04	191.01	0	0.07	1.06	4.09	15.81	0.05
<b>TSS</b>	2.32	6.62	43.85	284.43	0	0	30	3.48	11.63	0
<b>E. coli</b>	97.71	111.64	12463	114.26	8	53.5	430	1.55	1.73	14
<b>Total Coliform</b>	235.97	153.3	23502	64.96	13	216	610	0.94	0.76	315

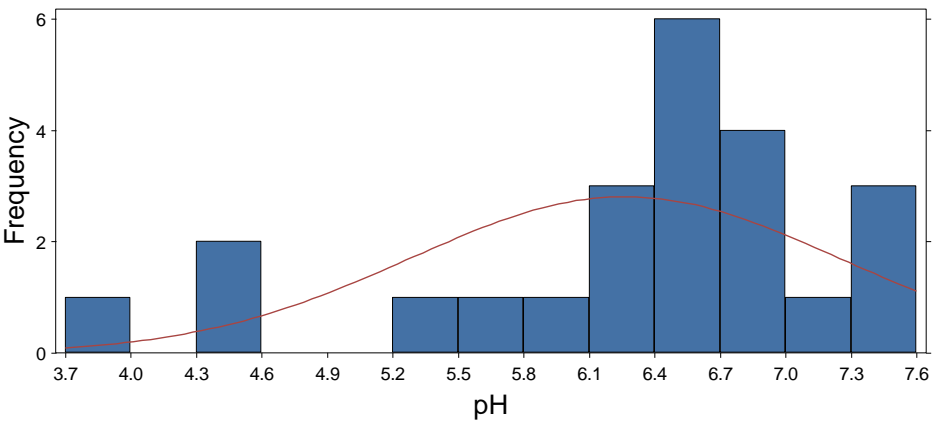
Table 2 above is the continuation of statistical summary. The second table consist of chemical parameters, heavy metals, trace elements and microbial indicators. Potassium values show a very high standard deviation of 22.24 which indicates variations from the mean values. The minimum and maximum values are 5.07 and 77.20 respectively. Iron (Fe) have mean, median and mode that have relatively close values of 0.05, 0.04, and 0.03 respectively. The closeness of the mean, mode and median could explain the relatively low standard deviation as the values are not spread out from the mean. The values also have positive skewness but a kurtosis greater than 3 thereby implying a non-normal data distribution. The sulphate distribution has mean value of 73.92 and a median of 79.50 with a relatively high mode of 93.0. The disparity between the points produced a standard deviation of 22.75 which is comparatively high. The data points are spread out with a minimum of 19.00 and maximum of 115.00 with 30.70 as coefficient of variance. The kurtosis is -0.05 which suggest near normality. The mean value for manganese is 0.20 with a relatively low standard deviation of 0.36. There is wide range between the mean and the median. Therefore, the CV is comparatively high as 180.48. Mn has a minimum of 0.0006 and maximum of 1.37 but with a kurtosis of 5.10, the data approaches non-normality. Nitrate shows mean value of 51.78 and median of 52.91 which are very close to imply a normal distribution. The values range from a minimum of 7.04 to maximum of 114.84. The kurtosis is -0.34 which is less than 3 for normal distribution. The reduced nitrogen (Nitrite) is not evenly distributed as there is wide spread between values. The mean value of 0.04 is far less than median 0.006 which is also greater than the mode of 0.00. Nitrite shows a minimum value of 0.00 and maximum of 0.23. The low values recorded for nitrite is responsible for the 0.00 mode value. All the trace elements and heavy metals such lead, zinc and arsenic recorded very low values as arsenic shows zero traces. The statistical distribution of the elements is not even with high non- normality in data points. Ammonium exhibited an uneven distribution as the mean of 0.58 is relatively higher than the median of 0.39 which is also lower than the mode of 0.00. The data has positive skewness but the kurtosis is as high as 8.01 which is way above 3 to suggest normality. Phosphate also shows very relatively low standard deviation thereby implying the points are not far from the mean. The element distribution has a mean value of 0.41, median of 0.17 and mode of 0.12. The CV is as high as 136.80 with a positive skewness. TSS are sparsely distributed with maximum value of 30.00 and minimum of 0.00. It has a median and mode of 0.00 with 2.32 mean. The sparse distribution of the data and the high CV of 248.43 makes it uneven and far from normal. In terms of biological indicators, E. coli

counts have a minimum value of 8.00 and a maximum value of 430.00. The bacteria are widely spread with a mean of 97.71 which is higher than the median of 53.50 which is also lower than the mode of 14. There is no closeness between the mean, median and mode thereby implying non-normality. The data points exhibited high level of variability with standard deviation of 111.64. Total Coliform on the other hand has a minimum count of 13.00 and maximum of 610.00. The mean value is 233.97 which is relatively closer to the median of 216.00 and a mode of 315.00. The closeness between the mean, mode and median coupled with a minimal kurtosis value of 0.76 suggest even distribution and normality between the data points.

#### **4.2 Histograms of water quality parameters in 5 slums in Accra**

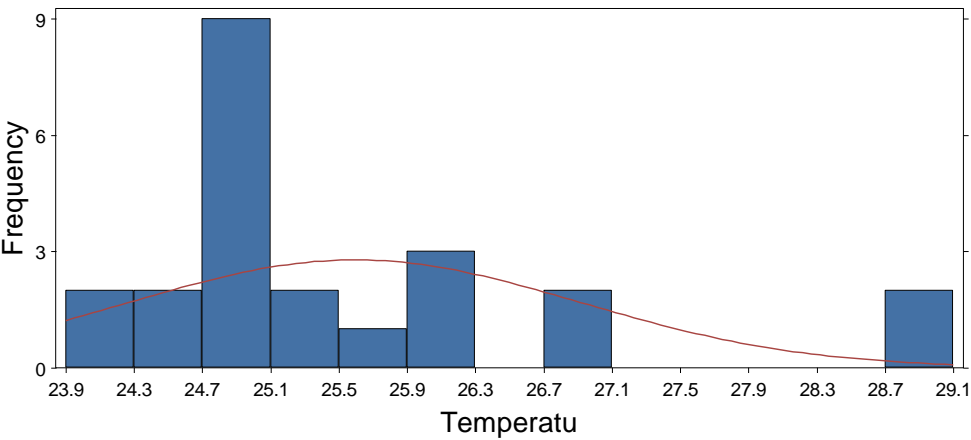
The histograms of water quality parameters for original and transformed data (where necessary) are shown in Figures 4.1 to 4.26. The histograms that showed non-normality were transformed by performing the base (10) logarithm of the original data. The normality of the histogram is dependent on the closeness of the mean, median and mode of the data. pH data is normalized due to the even distribution of the data points and the relationship between the mean, mode and median. In the case of physical parameters such as electrical conductivity and turbidity, the data for the histogram is non-normal due to the disparities between the mean, median and mode. The rest of the physical parameters that is total hardness and electrical conductivity failed to approach normality due to irregularities exhibited by the statistical parameters. Among the cations (fluoride, magnesium, potassium, sodium and manganese) all failed to reach normality except fluoride and potassium. Total alkalinity and bicarbonate are near normality but the non-existence of mode values due to the minimal values. The anion parameters (nitrate, nitrite, ammonium, phosphate, sulphate and chloride) are non-normal except nitrate and sulphate that exhibits near normality. The trace elements such as lead, iron, zinc and arsenic are all non-normal. Total suspended solids (TSS) exhibits normality in the data produced with same values of mode and median.

**pH**



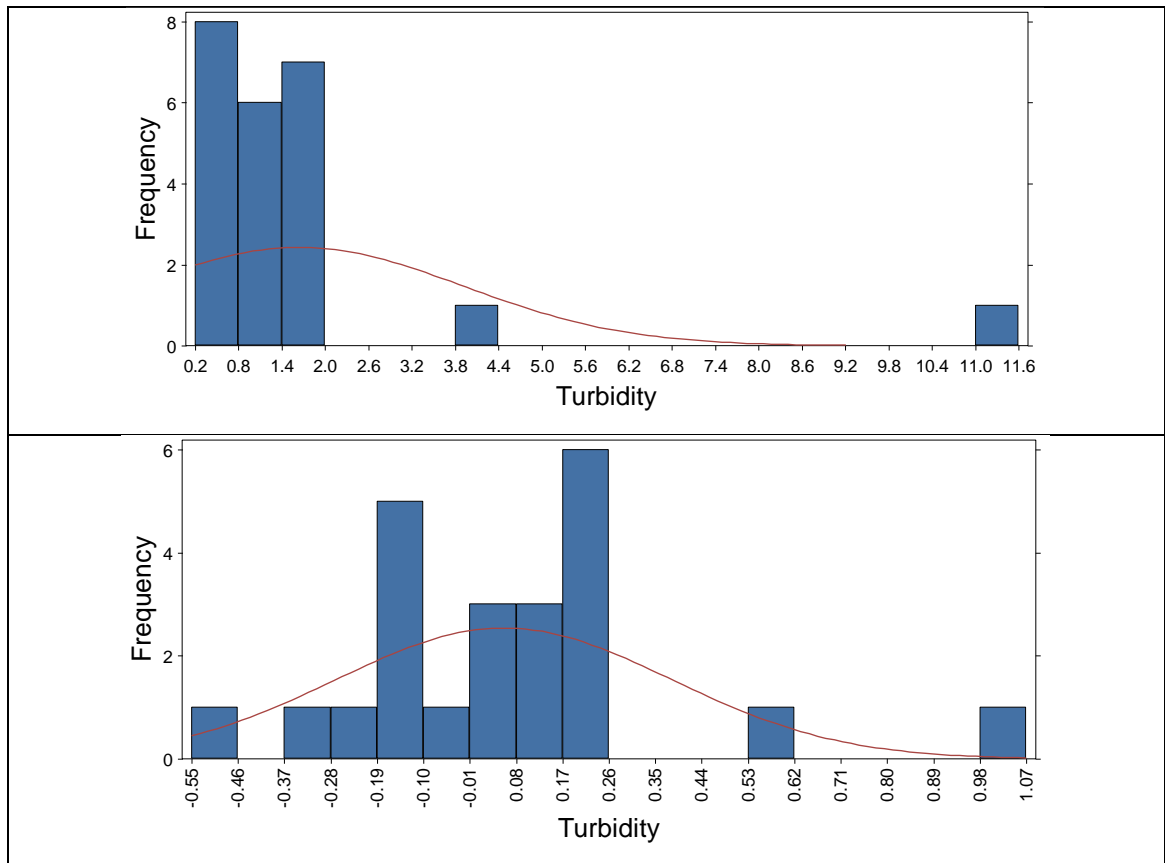
**Figure 4.1: Histogram of pH (original data)**

**Temperature**



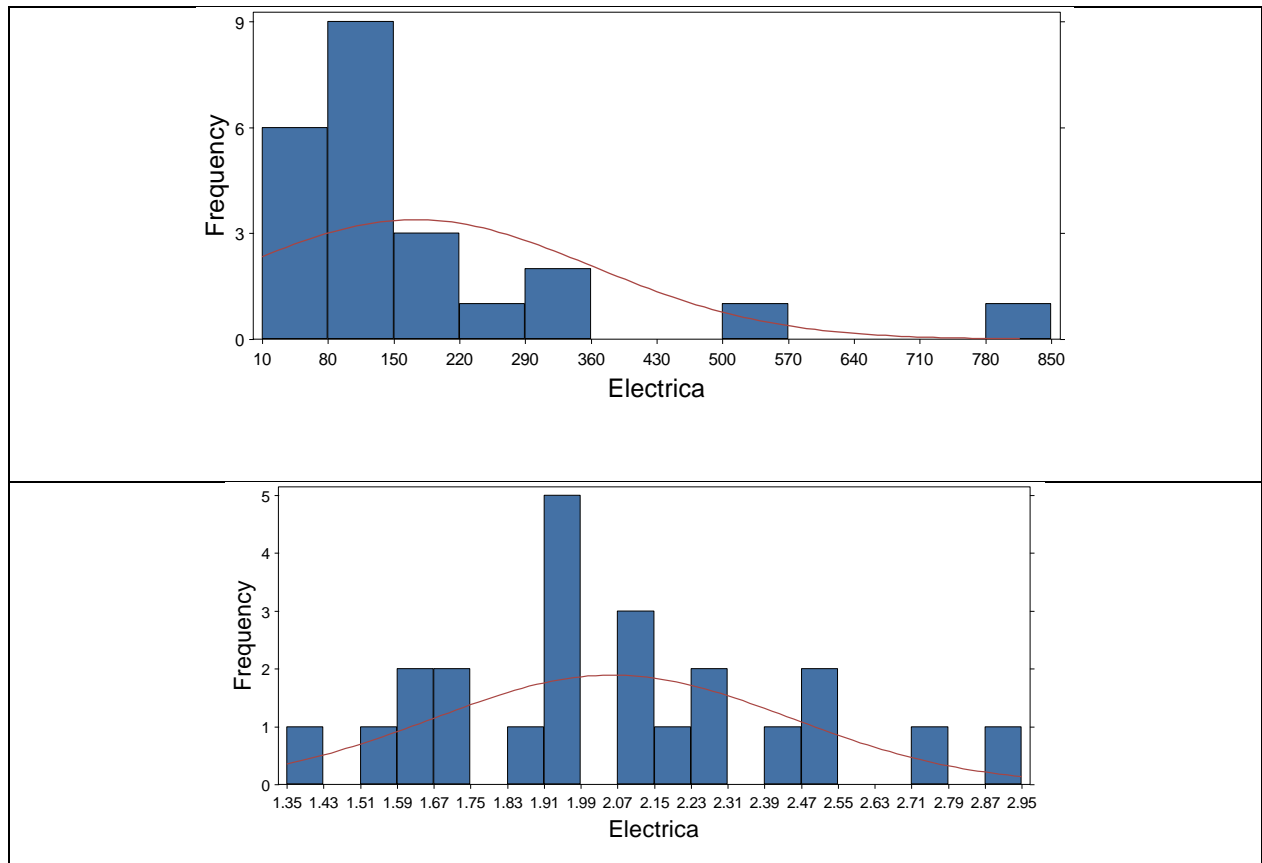
**Figure 4.2: Histogram of Temperature (original data)**

## Turbidity



**Figure 4.3: Histogram of Turbidity a) original data b) Log transformed data**

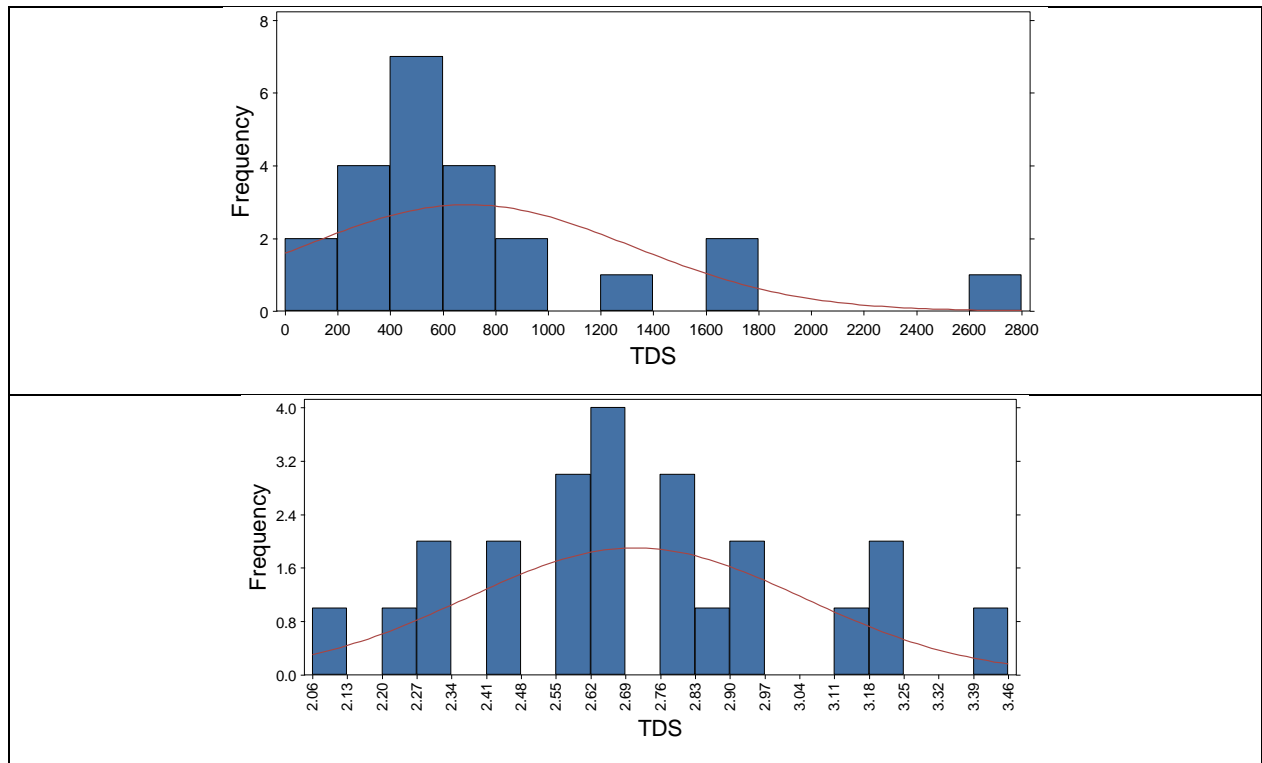
## Electrical conductivity



**Figure 4.4: Histogram of Electrical Conductivity a) original data b) log transformed data**

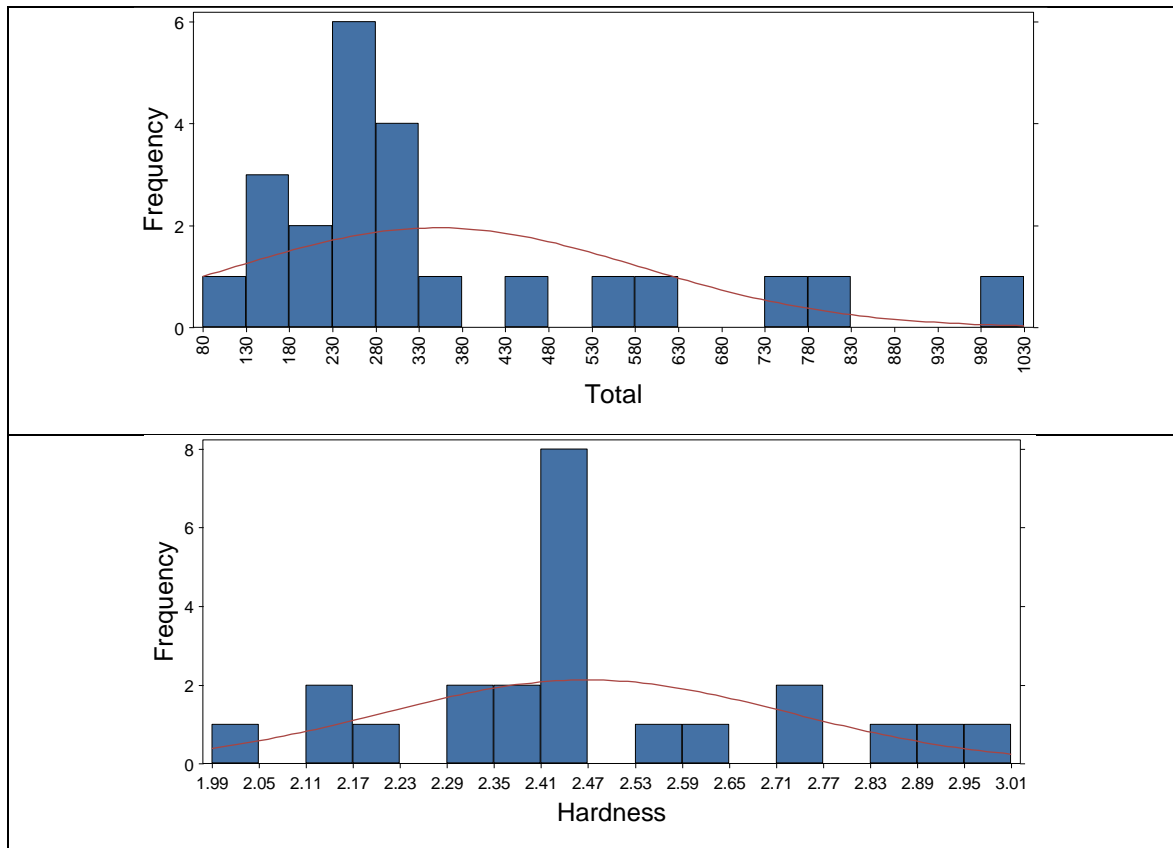


## Total Dissolved Solids (TDS)



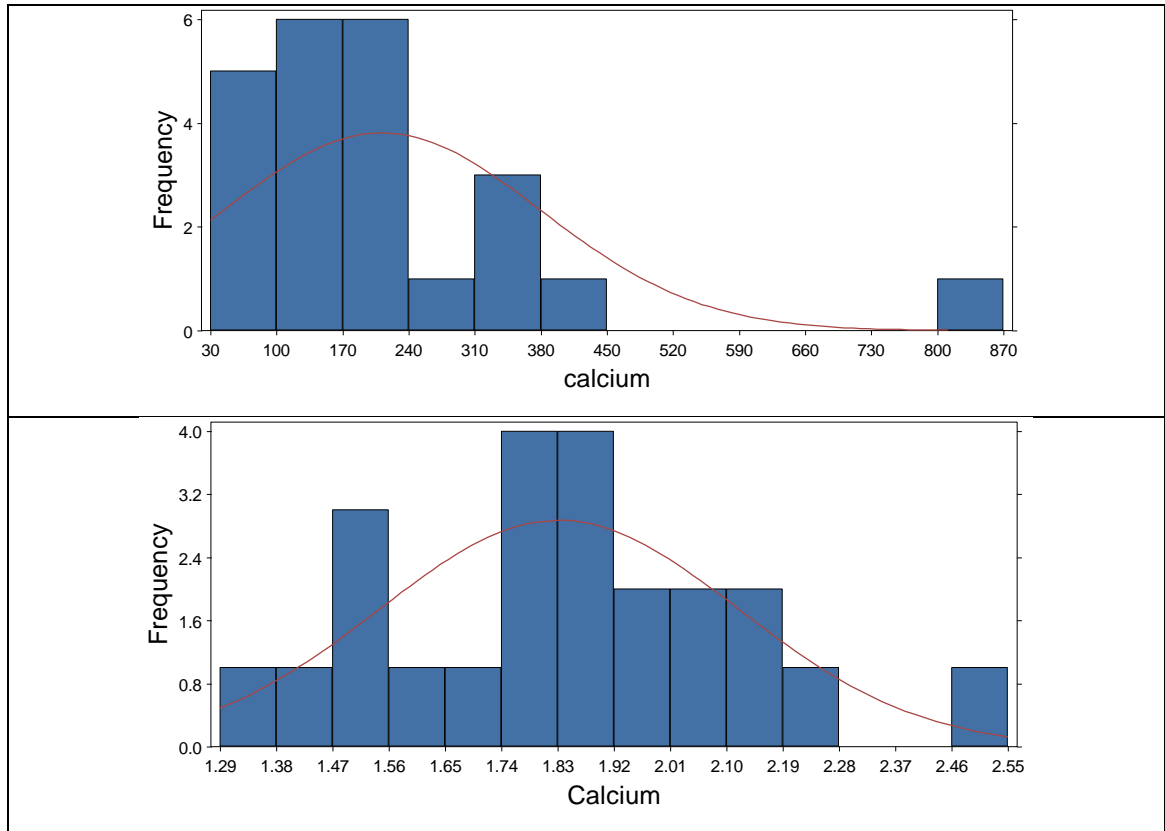
**Figure 4.5: Histogram of TDS a) original data b) log transformed data**

## Total hardness



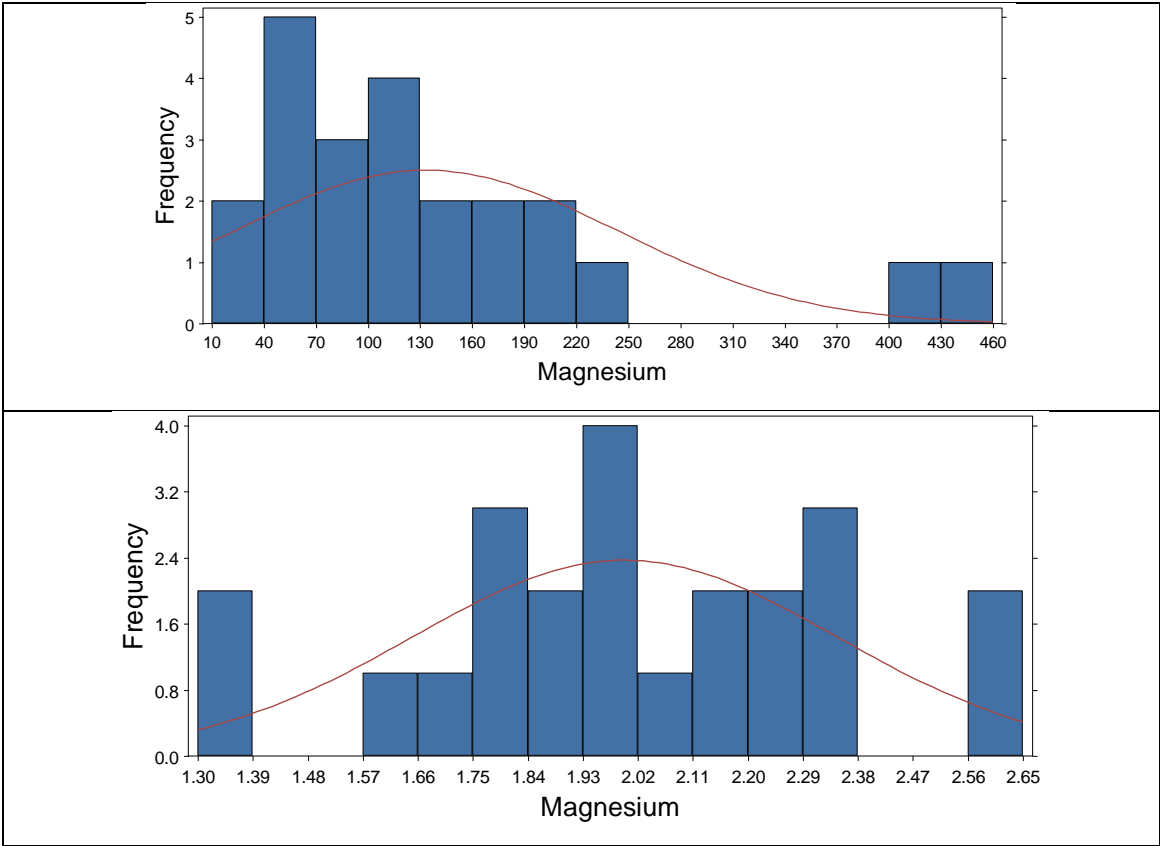
**Figure 4.6: Histogram of Total hardness a) original data b) log transformed data**

## Calcium



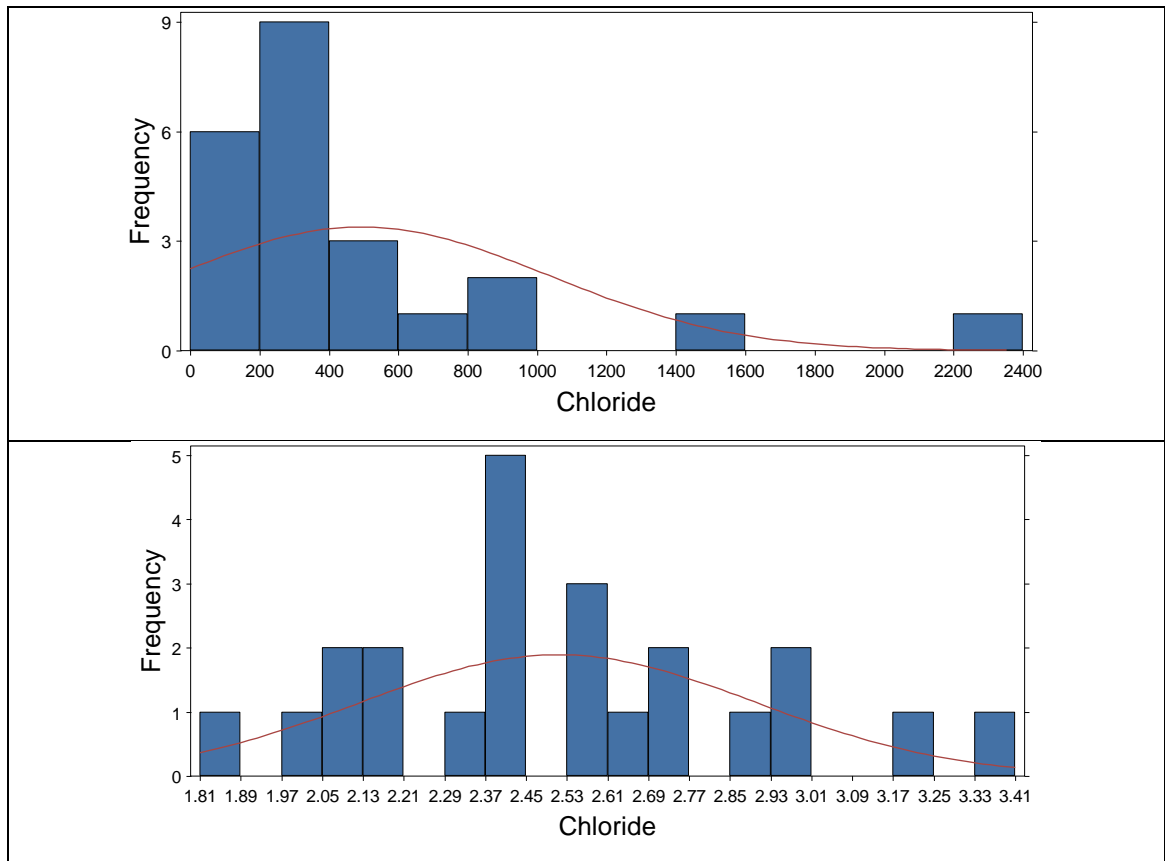
**Figure 4.7: Histogram of Calcium a) original data b) log transformed data**

**Magnesium**



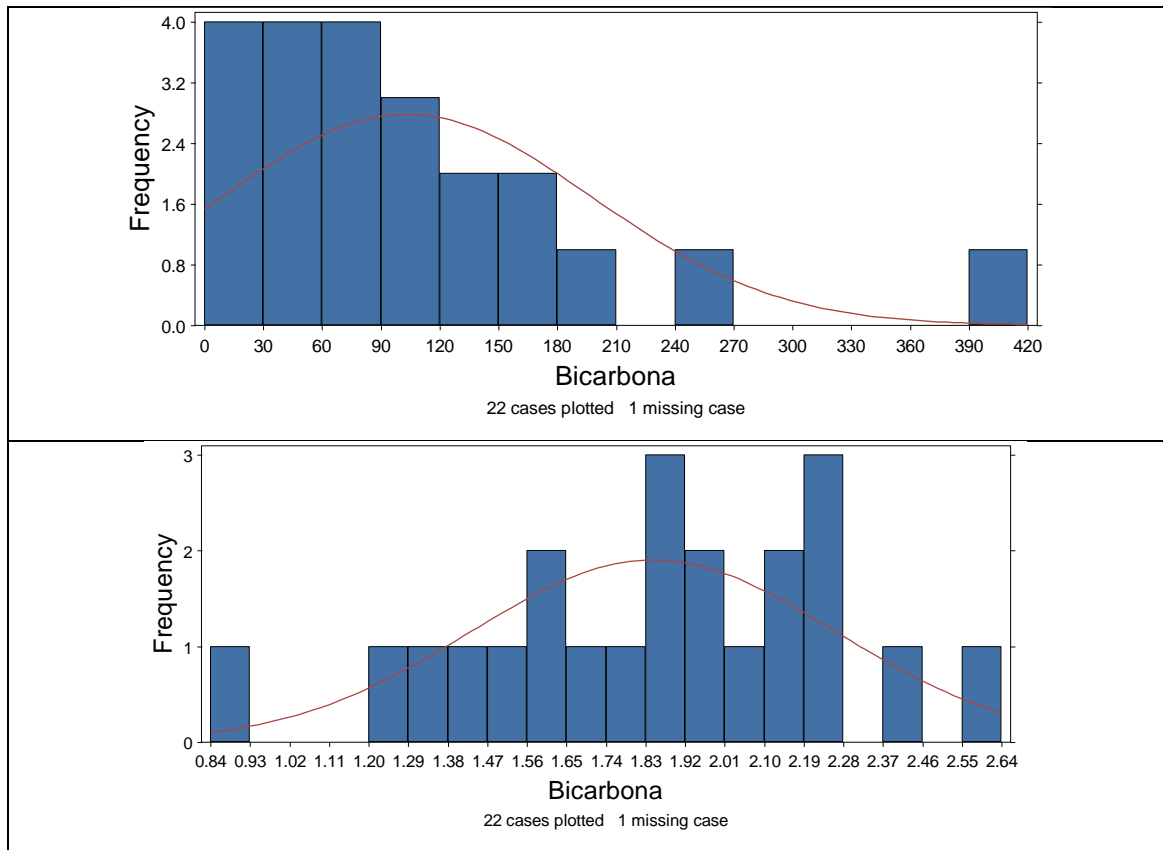
**Figure 4 .8: Histogram of Magnesium a) original data b) log transformed data**

## Chloride



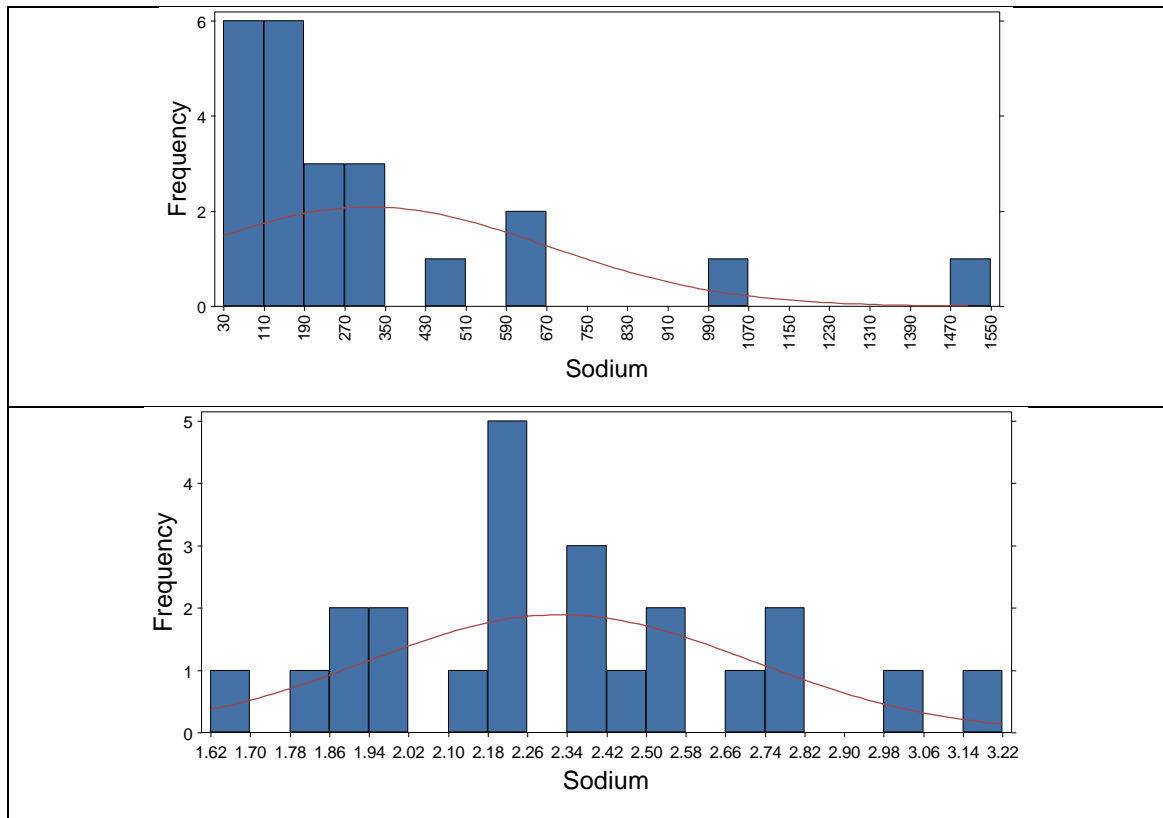
**Figure 4.9: Histogram of Chloride a) original data b) log transformed data**

## Bicarbonates



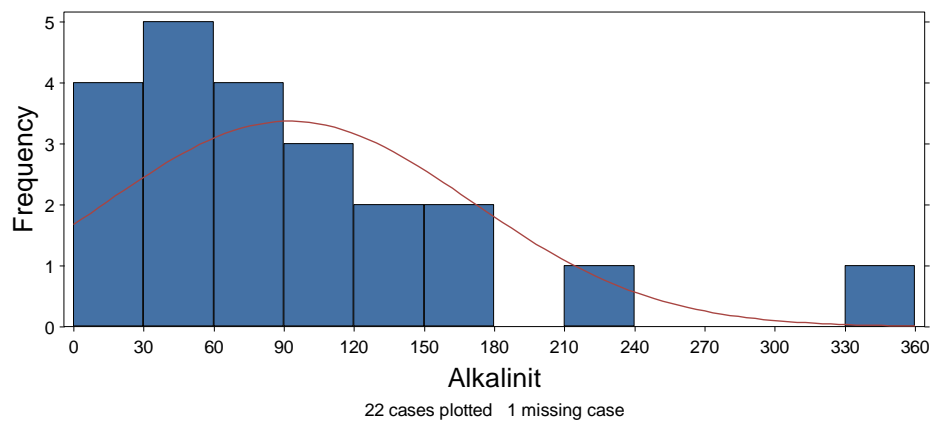
**Figure 4 .10: Histogram of Bicarbonate values A) original data b) log transformed data**

## Sodium



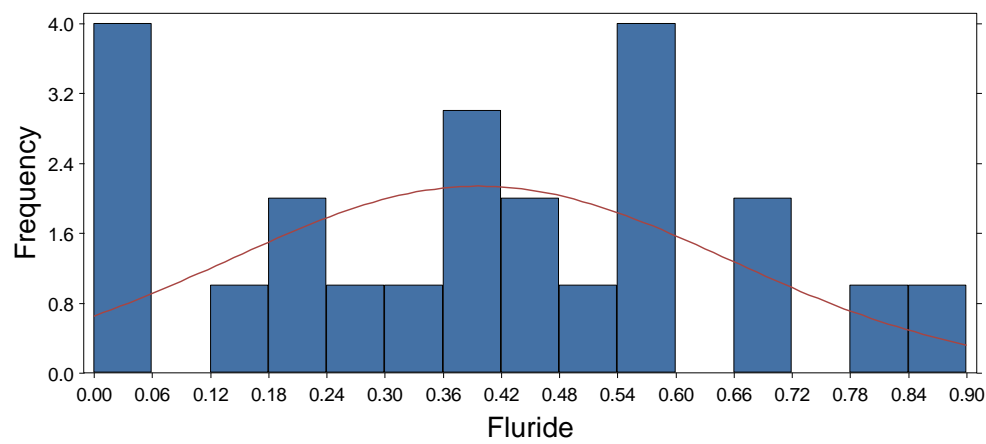
**Figure 4.11: Histogram of Sodium a) original data b) log transformed data**

## Total Alkalinity



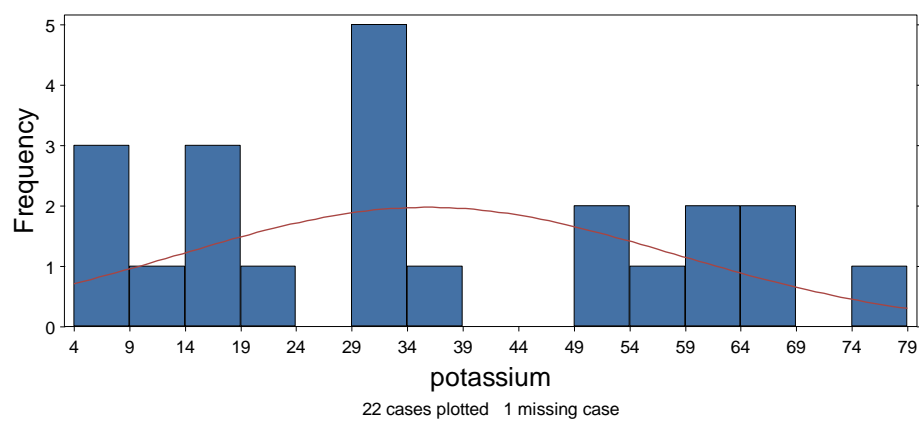
**Figure 4.12: Histogram of Total Alkalinity (original data)**

**Fluoride**



**Figure 4.13 Histograms of Fluoride (original data)**

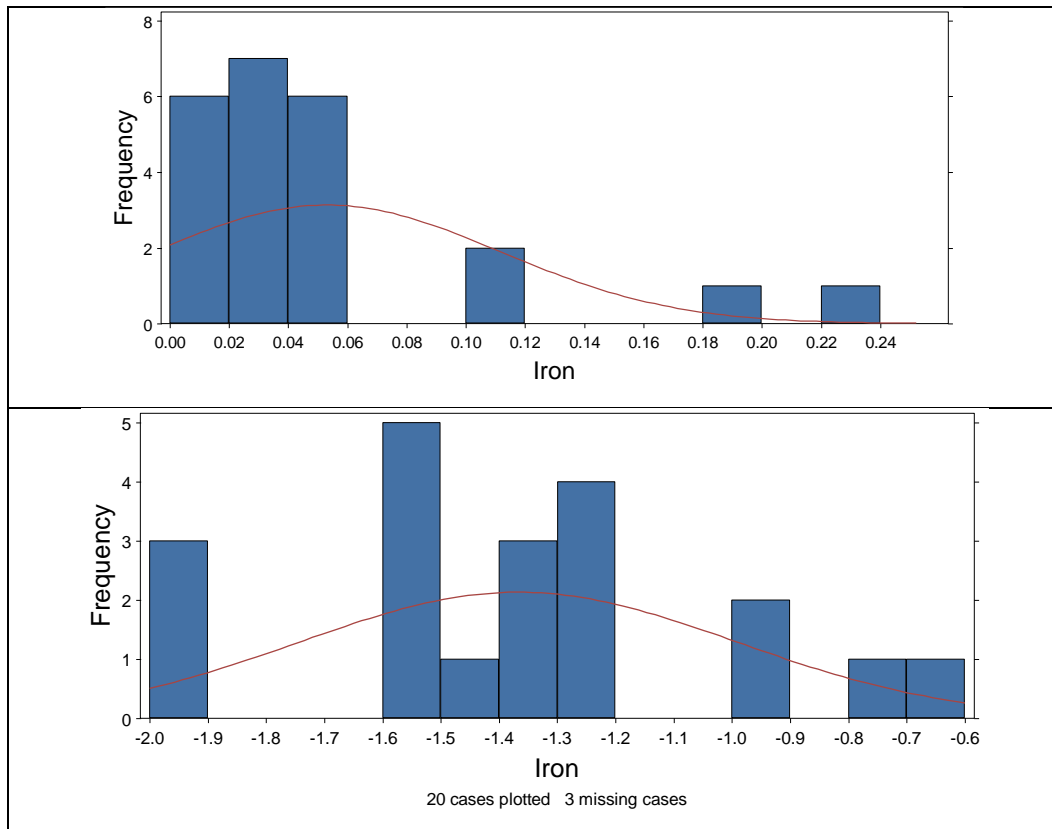
**Potassium**



**Figure 4.14:Histogram of Potassium (original data)**

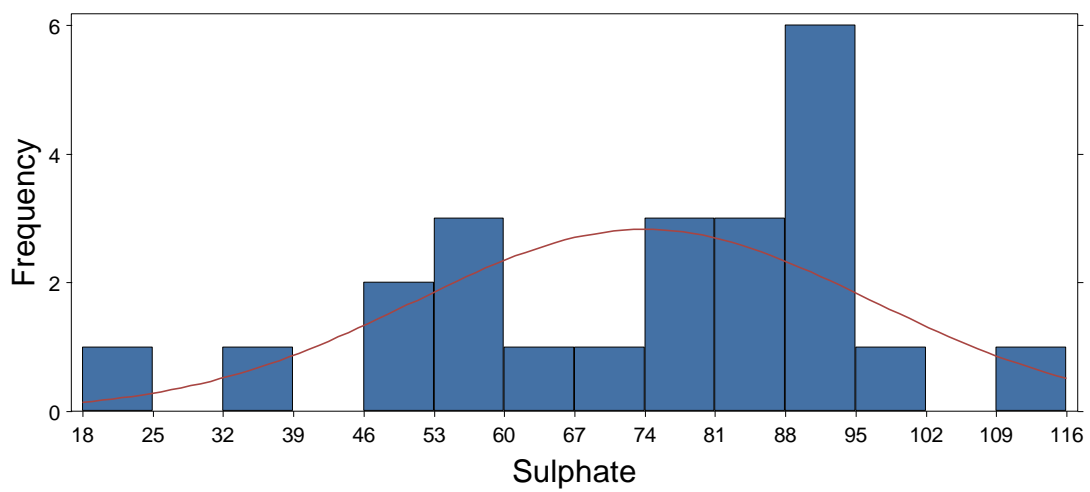


## Iron



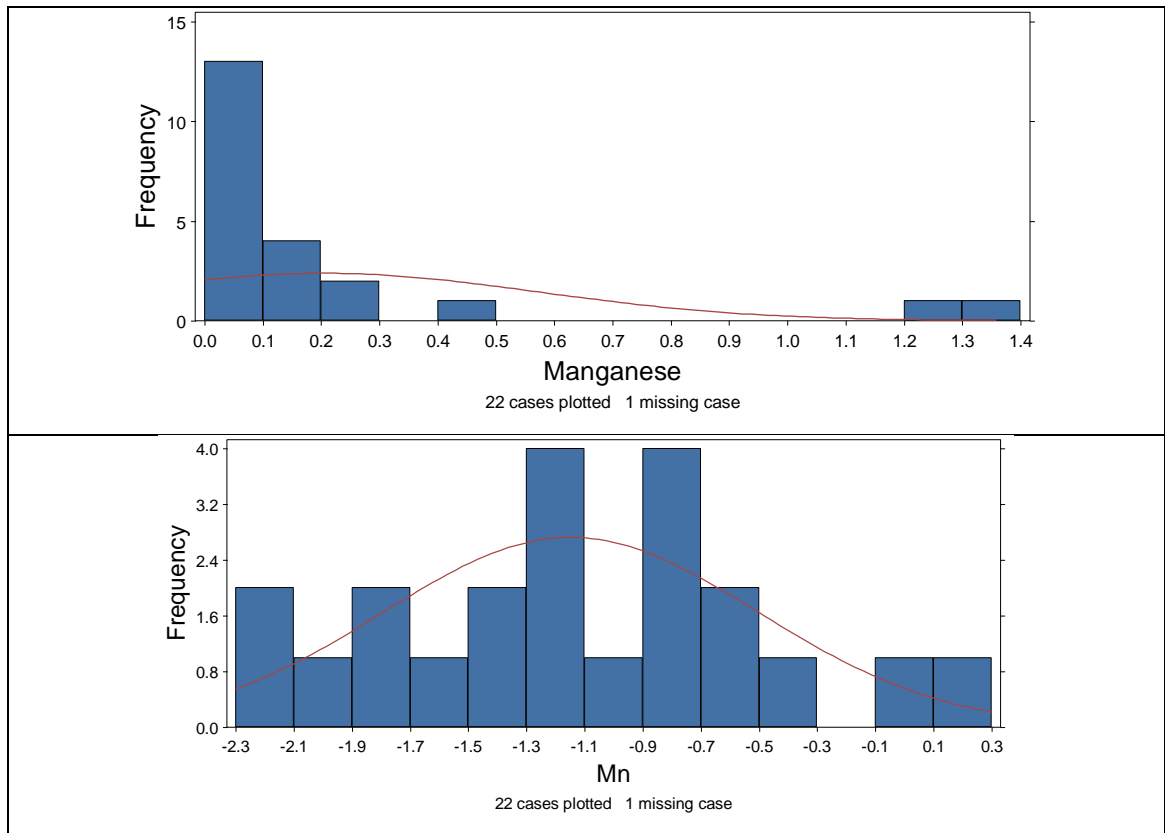
**Figure 4.15: Histogram of Iron a) original data b) log transformed data**

## Sulphate



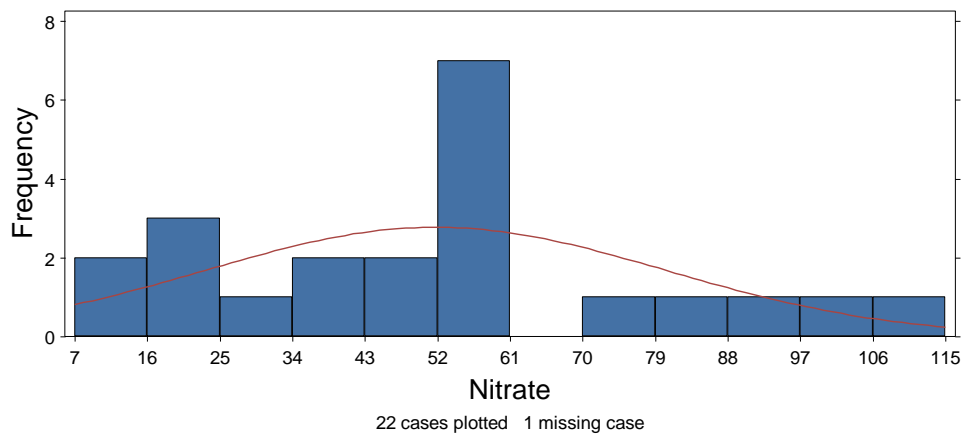
**Figure 4.16: Histogram of sulphate (original data)**

## Manganese



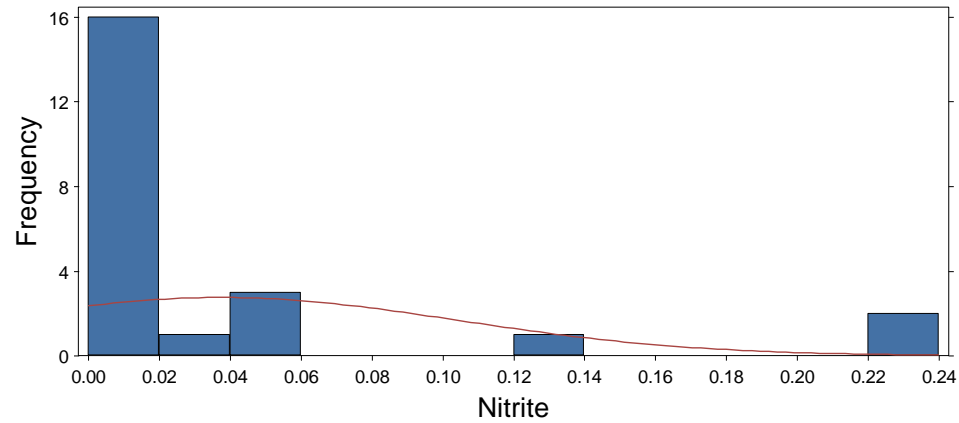
**Figure 4.17: Histogram of Manganese a) original data b) log transformed data**

## Nitrate



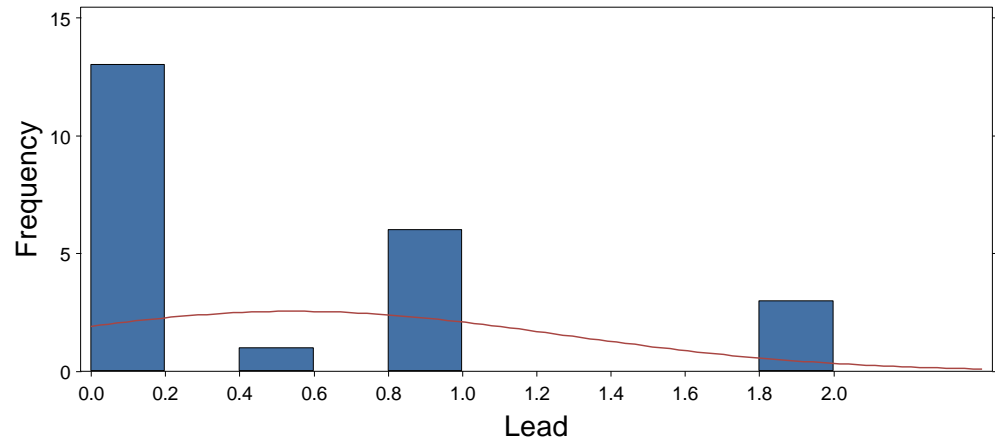
**Figure 4.18: Histogram of Nitrate(original)**

**Nitrite**



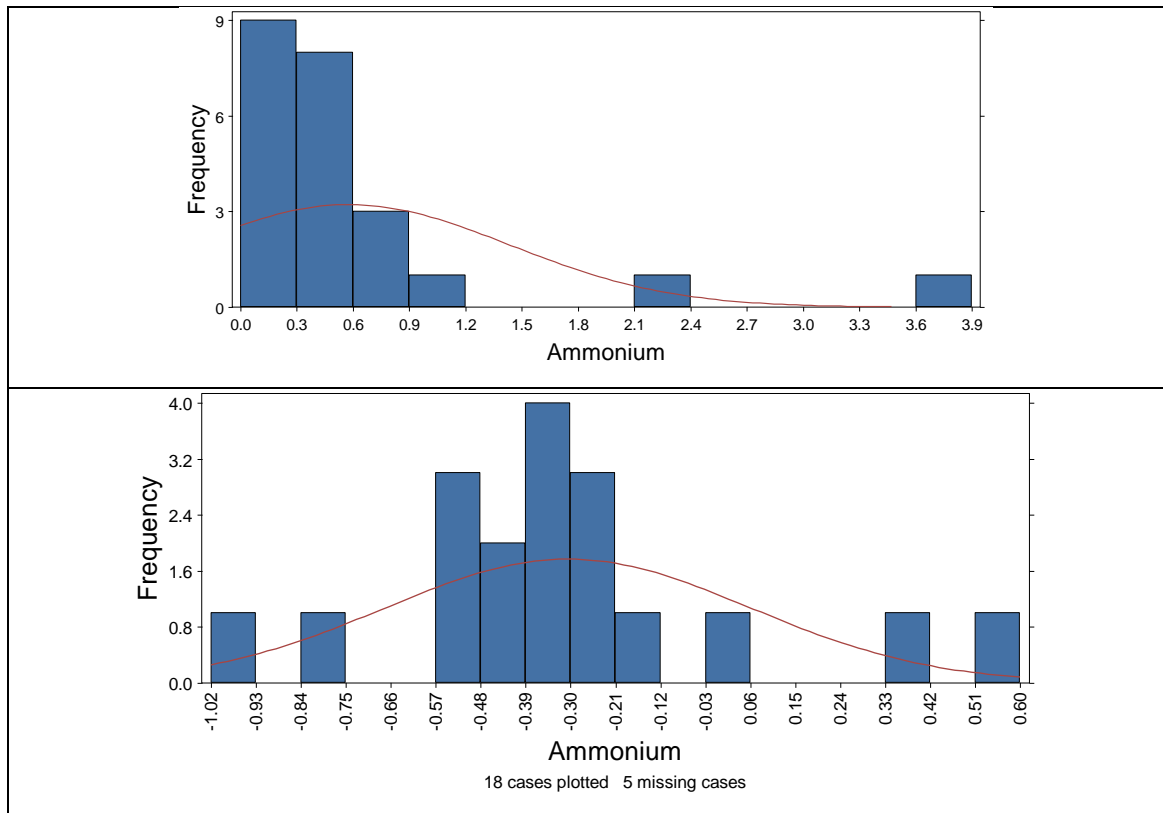
**Figure 4 .19: Histogram of Nitrite (original)**

**Lead**



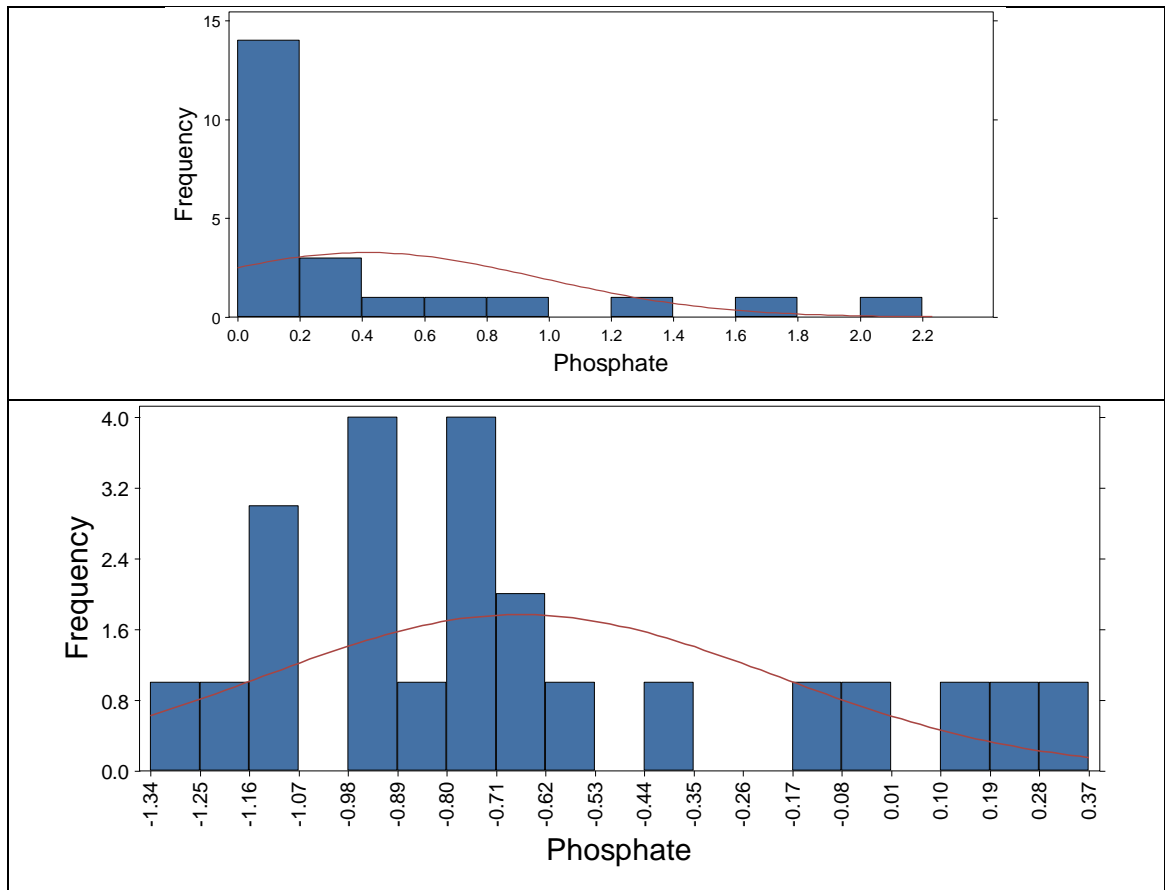
**Figure 4.20: Histogram of Lead (original)**

## Ammonium



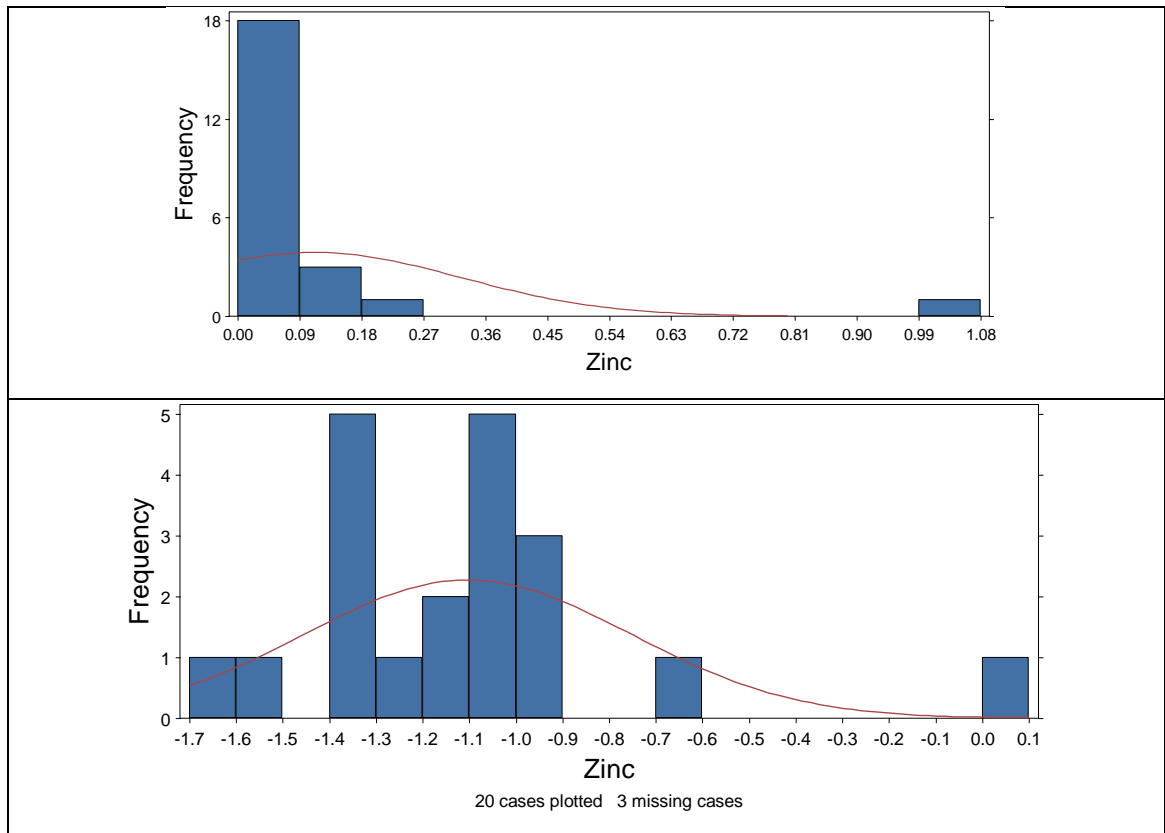
**Figure 4.21: Histogram of Ammonium a) original data b) log transformed data**

## Phosphate



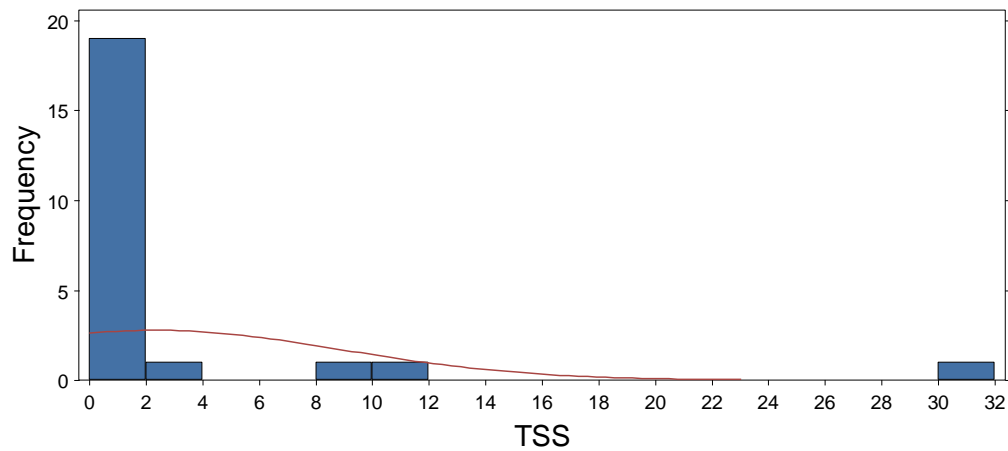
**Figure 4.22:** Histogram of Phosphate values a) original b) log transformed data

## Zinc



**Figure 4.23: Histogram of Zinc a) original data b) log transformed data**

## Total suspended solids

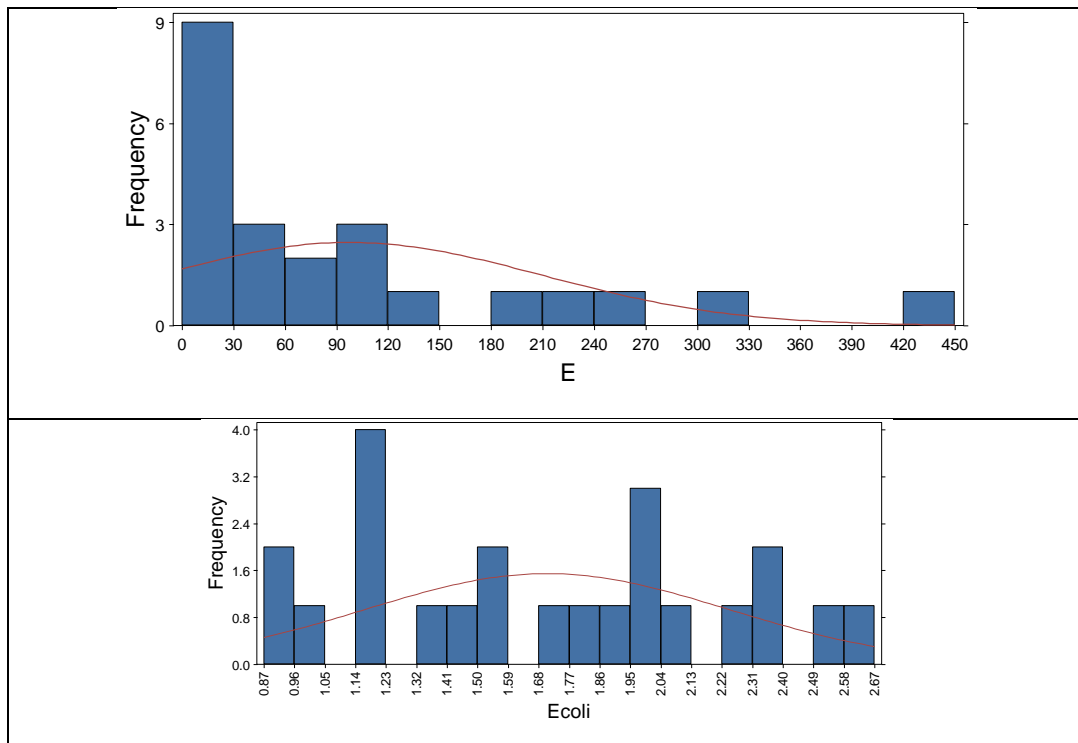


**Figure 4.24: Histogram of TSS (original data)**

In terms of biological constituents, *E. coli* (fig 4.25) count is non-normal but total coliform (fig 4.64) exhibits normality in the data processed. The parameters that exhibit non-normality were

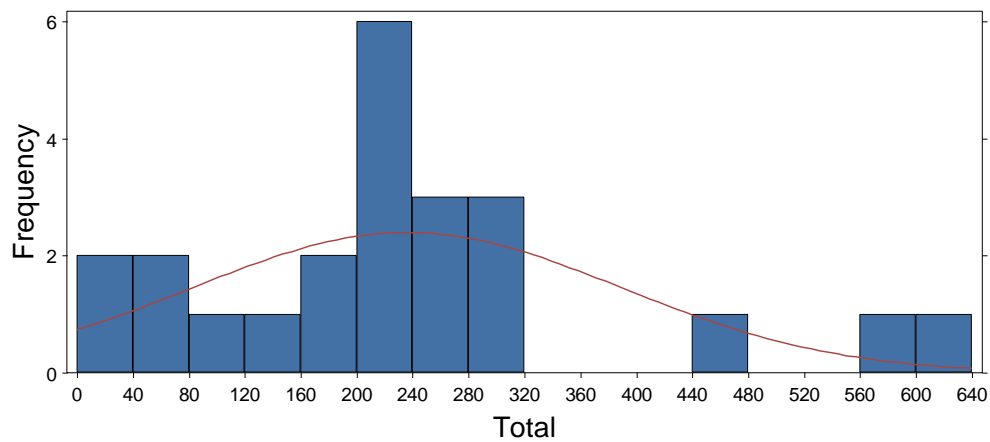
transformed in excel and the normalized histograms are produced in the figures below. The log transformed data shows even distribution of the coliform counts.

### E. coli



**Figure 4-25: Histogram of E. coli a) original b) log transformed data**

### Total coliform



**Figure 4.26: Histogram of Total Coliform (original data)**

### 4.3 Statistical Analysis of water quality parameters in 5 slums in Accra

Table 4.3: Analysis of variance for biological and chemical properties of groundwater in 5 slums in Accra (original data)

Treatment	pH	Temp	Tur	EC	TDS	HA	Ca	Mg	Cl <sup>-</sup>	HCO <sup>3-</sup>	Na	TA	F	K	
Nima	5.09b	25.75b	0.94a	147.05ab	735.25b	292.50b	60.00b	142.50ab	416.59ab	62.22a	270.37ab	51.00b	0.20b	28.10bc	
S.Zongo	7.35a	24.25c	0.985.00a	255.08ab	344.10bc	400.00b	89.00b	177.50ab	727.28ab	191.62a	472.00ab	196.00a	0.18b	48.53ab	
Chorkor	6.09ab	25.25b	1.42a	372.47a	1862.40a	717.50a	185.00a	255.00a	1063.4a	100.04a	690.16a	82.00b	0.54a	27.45bc	
Jamestown	6.52a	28.00a	3.69a	79.78b	398.50bc	215.00b	62.00b	60.00b	227.43b	91.50a	147.6b	75.00b	0.56a	60.18a	
Pantang	6.17ab	25.00bc	1.54a	42.03b	210.13c	167.50b	44.00b	57.50b	119.95b	77.47a	77.854b	63.50b	0.59a	15.85c	
Analysis of Variance															
Source of variation		df													
		pH	Temp	Tur	EC	TDS	TH	Ca	Mg	Cl <sup>-</sup>	HCO <sup>3-</sup>	Na	TA	F	K
p values		0.0252	0	0.5185	0.115	0	0.0028	0.0174	0.0632	0.1153	0.4114	0.1153	0.0637	0.0156	0.0281
Slum	4	2.66	8.08	5.13	72848.10	1809396	192033	80037.5	27832.5	594193	10297	250268	13687	0.18	1282.84
Error (MS)	15	0.69	0.35	6.08	32708.7	89218.0	28862.00	18950	9888.3	267113	9742.3	112507	4875.9	0.04	349.16
Total	19														



Table 4.4: Analysis of variance for biological and chemical properties of groundwater in 5 slums in Accra (continued) (original data)

Treatment	Fe	S	Mn	NO <sup>3-</sup>	NO <sup>2-</sup>	pb	NH <sup>4+</sup>	PO <sup>4</sup> <sup>3-</sup>	As	Zn	TSS	E. coli	TC
Nima	0.03b	60.50b	0.11b	67.43ab	0.06a	0.25bc	1.31a	0.29ab		0.05a	0.25b	18.25c	90.75c
S.Zongo	0.02b	85.25a	0.029b	54.12ab	0.07a	0c	0.31a	0.64ab		0.11a	0.00b	149.75ab	237.75b
Chorkor	0.13a	87.75a	0.73a	27.06b	0.06a	1.00ab	0.56a	0.11b		0.03a	0.00b	12.50c	162.75bc
Jamestown	0.05ab	91.00a	0.06b	73.48a	0.00a	0.25bc	0.11a	0.97a		0.33a	0.00b	89.50bc	185.25bc
Pantang	0.05ab	39.25b	0.12b	36.41ab	0.00a	1.50a	0.78a	0.17b		0.06a	12.50a	249.00a	490.25a

Analysis of Variance

Source of variation	df	Fe	S	Mn	NO <sup>3-</sup>	NO <sup>2-</sup>	Pb	NH <sup>4+</sup>	PO <sup>4</sup> <sup>3-</sup>	As	Zn	TSS	E. coli	TC
p values		0.1297	0.0004	0.0291	0.1208	0.5922	0.0076	0.4177	0.2093	M	0.314	0.02	0.0067	0.0003
Slum	4	0.00	1986.63	0.35	1568.57	0.00	1.58	0.86	0.52	0.00	0.06	123.80	39053.40	93649.7
Error (MS)	15	0.00	201.02	0.09	719.53	0.00	0.30	0.82	0.31	0.00	0.05	30.52	7215.80	9031.3
Total	19													

*Table 4.5: Analysis of variance for biological and chemical properties of groundwater in 5 slums in Accra (transformed data)*

#### 4.4. Geospatial Analysis of groundwater quality parameters in 5 slums in Accra

A geospatial analysis was also conducted on the data to see the actual distribution of water quality properties across the slums. In order to accomplish this task, the coordinates of each water sampling location were recorded into a global positioning system device (GPS). The coordinates were entered into Microsoft excel and imported to ArcGIS for spatial mapping of the well locations and the level of quality parameter concentrations. The same procedure was repeated for the creation of Variogram models using GS+ software. The spatial distribution maps and variograms are represented in the figures below.

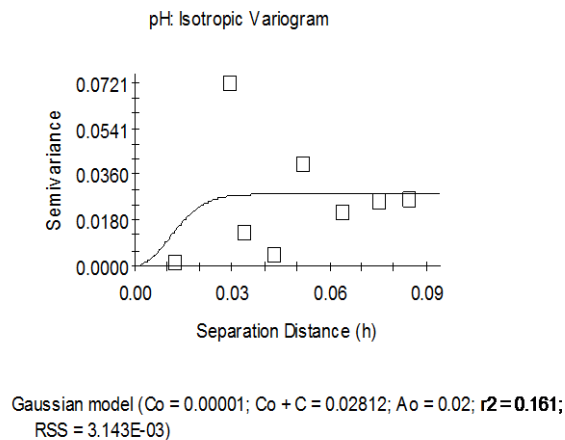
**Table 4.6: Parameters of Variogram models for groundwater quality in the five (5) selected slums with Accra**

Water quality parameter	Model	Co	Co+C	Ao	R <sup>2</sup>
Ph	Gaussian	0.00	0.02	0.02	0.16
Turbidity	Gaussian	0.01	3.63	0.02	0.07
EC	Gaussian	7400.00	85900.00	0.12	0.36
TDS	Gaussian	80000.00	2270000	0.12	0.34
Total Hardness	Gaussian	19200.00	49400.00	0.13	0.32
Chloride	Gaussian	64000.00	639000.00	0.11	0.36
Calcium	Gaussian	930.00	22960.00	0.03	0.107
Magnesium	Spherical	117.00	1640.00	0.10	0.52
Ammonium	Gaussian	0.00	0.27	0.01	0.00
Manganese	Gaussian	0.15	2.30	0.15	0.44
Fluoride	Gaussian	0.01	0.72	0.23	0.48
Iron	Gaussian	0.00	0.00	0.00	0.00
Nitrate	Gaussian	435.00	2930.00	0.17	0.29
Nitrite	Gaussian	0.00	0.00	0.01	0.03
Phosphate	Gaussian	0.00	0.14	0.01	0.05
Sulphate	Gaussian	78.00	2785.00	0.07	0.31
Sodium	Gaussian	25000.00	381000.00	0.13	0.37
TSS	Gaussian	0.01	18.01	0.01	0.02

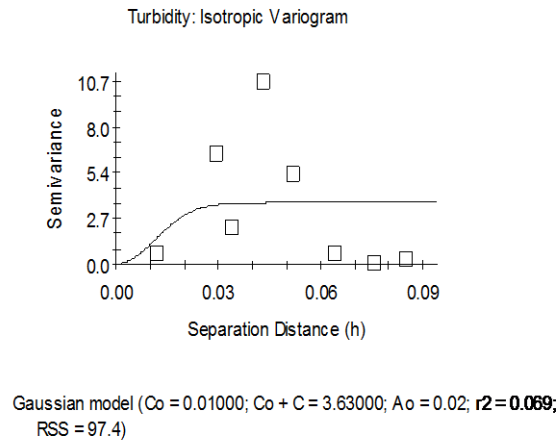
<b>Zinc</b>	Gaussian	0.00	0.004	0.01	0.02
<b>Lead</b>	Exponential	0.32	0.88	0.02	0.018
<b>E. coli</b>	Gaussian	3100.00	57300.00	0.11	0.39
<b>Total Coliform</b>	Exponential	2700.00	218400.00	0.28	0.24

#### 4.6.1 Variograms of Water quality parameters

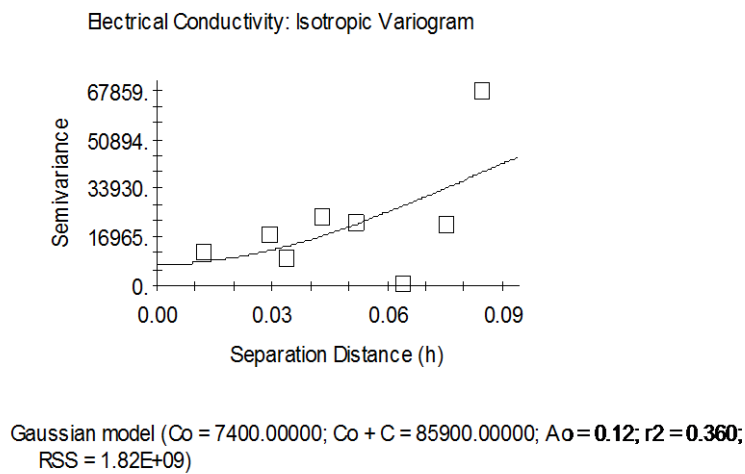
Variograms of pH (figure 4.27), Turbidity (figure 4.28), Electrical Conductivity (figure 4.29) and Total Suspended Solids (TDS) (figure 4.30) are presented in the figures below. All the parameters are represented by the Gaussian model except for lead, magnesium and total coliform which are represented by exponential and spherical models. The  $A_0$  (range of spatial variability) for pH and Turbidity is the same which is 0.02. The parameters having the same range of spatial variability imply that they can be sampled together with no impact on distance variations. The sill values for both parameters are closer to zero (0) except for turbidity that has a sill value of 3.6. The case is the same for TDS and electrical conductivity. The two parameters are dependent on each other physiochemically. TDS and EC have the same  $A_0$  value of 0.12 with the  $r^2$  values are 0.34 and 0.36 respectively. The values are far away from 1 so not significant.



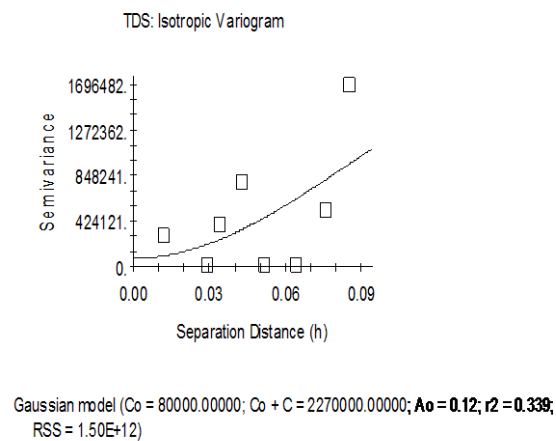
**Figure 4.27: showing the Variogram of pH**



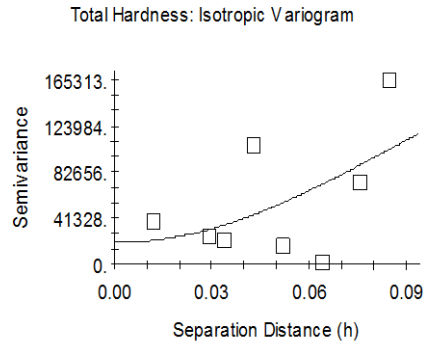
**Figure 4.28: showing variogram of Turbidity**



**Figure 4.29: showing the variogram of EC**

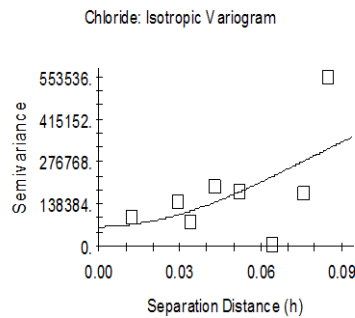


**Figure 4.30: showing the variogram of TDS**



Gaussian model ( $C_0 = 19200.00000$ ;  $C_0 + C = 249400.00000$ ;  $A_0 = 0.13$ ;  $r^2 = 0.320$ ;  $RSS = 1.47E+10$ )

**Figure 4.31: showing the variogram of TH**

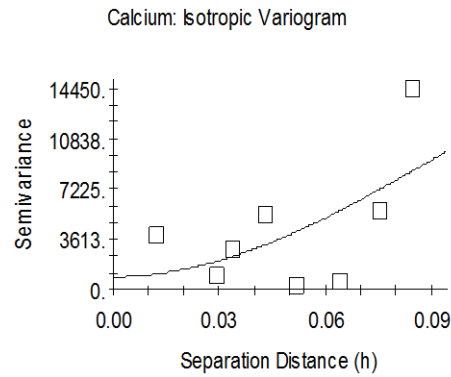


Gaussian model ( $C_0 = 64000.00000$ ;  $C_0 + C = 639000.00000$ ;  $A_0 = 0.11$ ;  $r^2 = 0.356$ ;  $RSS = 1.22E+11$ )

**Figure 4.32: showing the variogram Chloride**

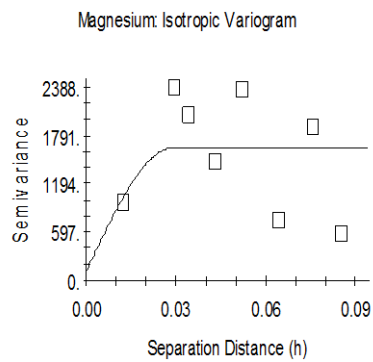
The figures above represent the variograms for total hardness (TH) (figure4.31) and chloride (figure 4.32). The variograms are represented by the Gaussian model with  $A_0$  values ranging from 0.11 to 0.13 which implies slight difference in spatial variability. The two parameters have  $r^2$  values of 0.32 and 0.35 with less significance.

The variograms of calcium and magnesium in figure 4.33 and 4.34 below have similar trend of spatially variability. The similarity between the  $A_0$  values of 0.13 and 0.03 implies dependence of the two parameters on the same sampling distance. Magnesium has  $r^2$  value of 0.12 which shows no significance compared to calcium with 0.37  $r^2$ . Calcium is represented by Gaussian model while magnesium is represented by spherical model.



Gaussian model ( $C_0 = 930.00000$ ;  $C_0 + C = 22960.00000$ ;  $A_0 = 0.13$ ;  $r_2 = 0.386$ ;  
 RSS =  $9.16E+07$ )

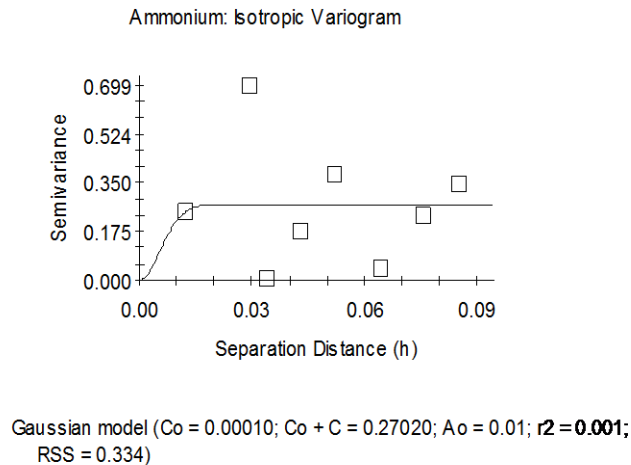
**Figure 4.33: showing the Variogram of Calcium**



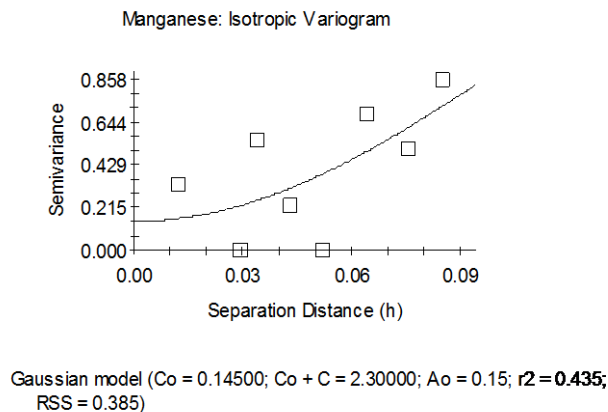
Spherical model ( $C_0 = 117.00000$ ;  $C_0 + C = 1640.00000$ ;  $A_0 = 0.03$ ;  $r_2 = 0.107$ ;  
 RSS = 3261420.)

**Figure 4.34: showing the Variogram of Magnesium**

The variogram of Manganese (figure 4.36) and Ammonium (4.35) are represented by Gaussian models. Ammonium has  $A_0$  value of 0.01 and  $r^2$  of 0.00 which is not significant. Manganese has  $r^2$  of 0.44 which is relatively significant for the sample size. The parameters have a similar spatial variability.

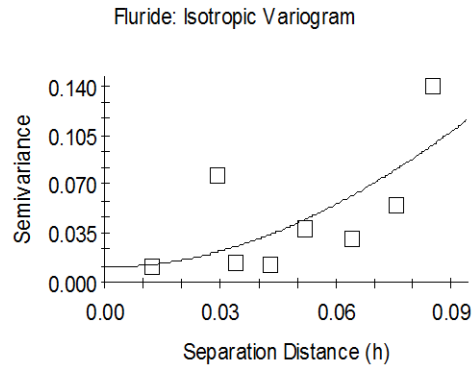


**Figure 4.35: showing the variogram, of Ammonium**



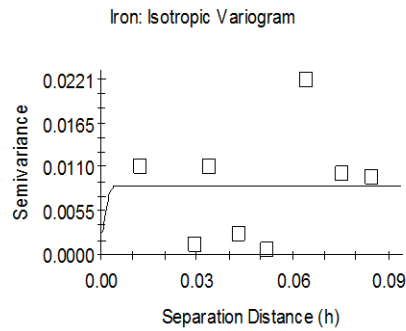
**Figure 4.36: showing the variogram of Manganese**





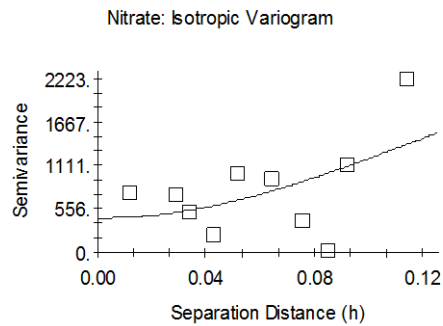
Gaussian model ( $C_0 = 0.01100$ ;  $C_0 + C = 0.71800$ ;  $A_0 = 0.23$ ;  $r^2 = \mathbf{0.479}$ ;  
 RSS = 7.079E-03)

**Figure 4.37: showing the variogram of Fluoride**



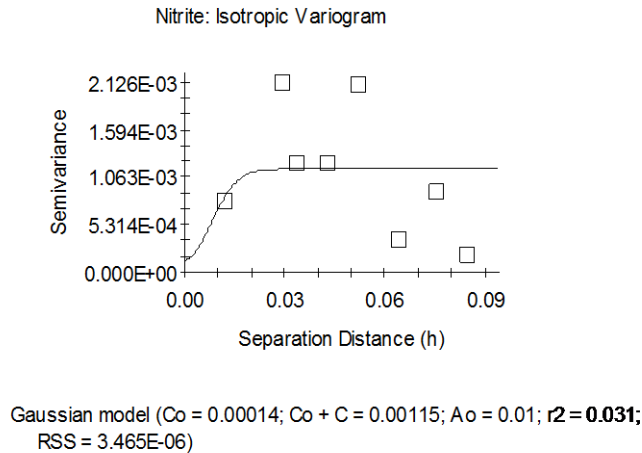
Gaussian model ( $C_0 = 0.00269$ ;  $C_0 + C = 0.00868$ ;  $A_0 = 0.00$ ;  $r^2 = \mathbf{0.000}$ ;  
 RSS = 3.478E-04)

**Figure 4.38: showing the variogram of Iron**



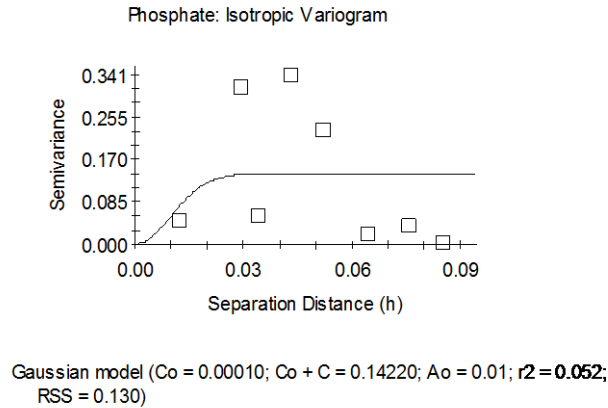
Gaussian model ( $C_0 = 435.00000$ ;  $C_0 + C = 2980.00000$ ;  $A_0 = \mathbf{0.17}$ ;  $r^2 = \mathbf{0.297}$ ;  
 RSS = 2399660.)

**Figure 4.39: showing the variogram of Nitrate**

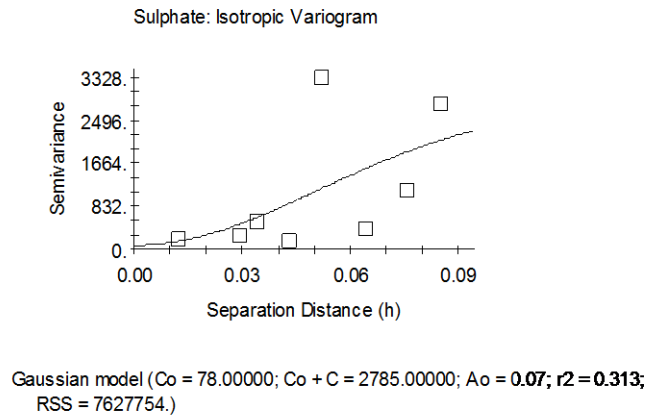


**Figure 4.40: showing the variogram of Nitrite**

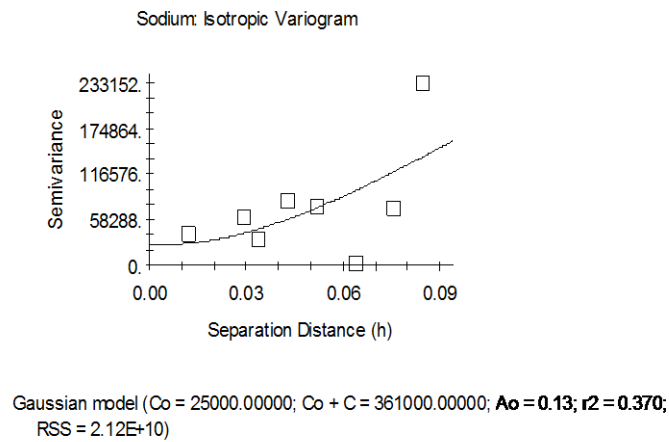
The figures above are variograms represented by Gaussian models for fluoride, iron, nitrate and nitrite. Iron (figure 4.38) and Nitrite (figure 4.40) are not significant as their  $r^2$  values approached zero (0). Nitrate (figure 4.39) and fluoride (figure 4.37) are relatively significant with  $r^2$  values of 0.3 and 0.5 respectively. The spatial variability of iron and nitrite are the same with no significance. The sill values for all the parameters approached zero except for nitrate.



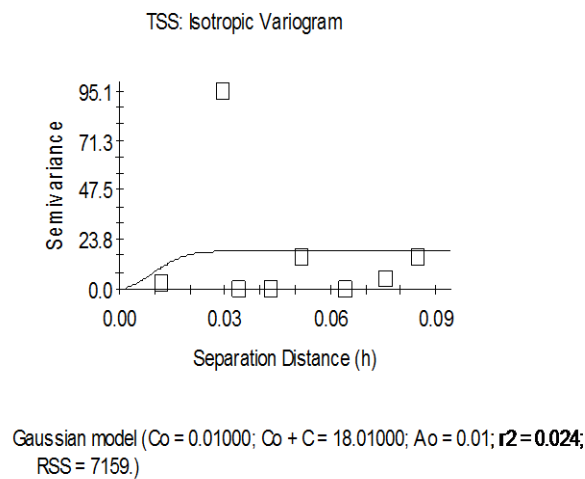
**Figure 4.41: showing the variogram of Phosphate**



**Figure 4.42: showing variogram of Sulphate**

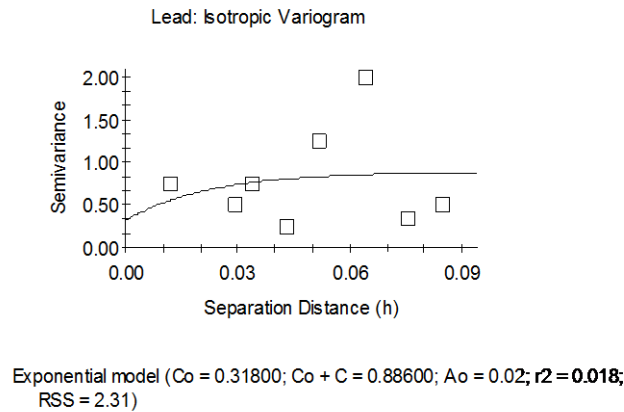


**Figure 4.43: showing the variogram of Sodium**

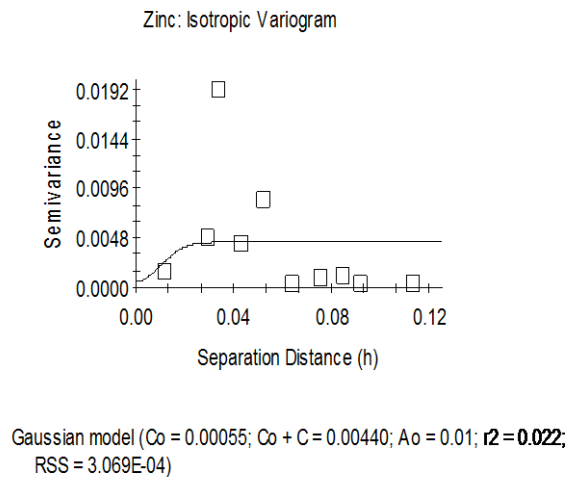


**Figure 4.44: showing the variogram of TSS**

Phosphate, sulphate, sodium and TSS of figure 4.41 to figure 4.44 are all represented by the Gaussian model. The parameters have  $r^2$  from 0.02, 0.05, 0.31 and 0.37 for TSS, sulphate, phosphate and sodium respectively. The relative weakness of the  $r^2$  values imply less significance. TSS and Phosphate have the same  $A_0$  values which suggest those parameters have the same spatial variability. None of the sill values of the parameters approached zero.

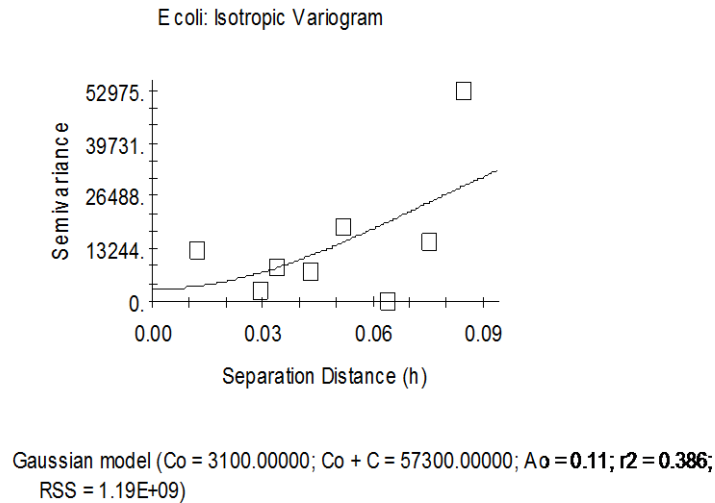


**Figure 4.45: showing the variogram of Lead**



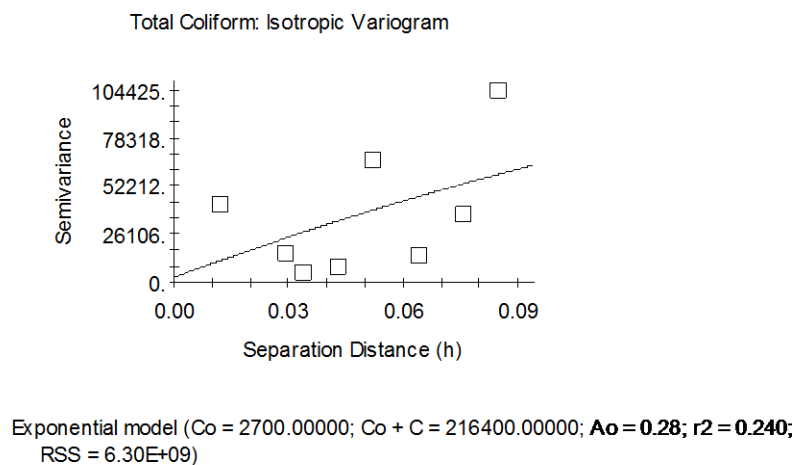
**Figure 4.46: showing the variogram of Zinc**

Unlike most of the other parameters, lead (figure 4.45) is represented by an exponential model. The  $r^2$  is 0.018 and a spatial variability of 0.02. The low  $r^2$  values the structure is not well developed and it is less significant. Zinc (figure 4.46) shows less significance as  $r^2$  values of 0.12 for zinc in the Gaussian model. The sill value for Zinc approaches zero while that of lead is 0.88.



**Figure 4.47: showing the variogram of E. coli**

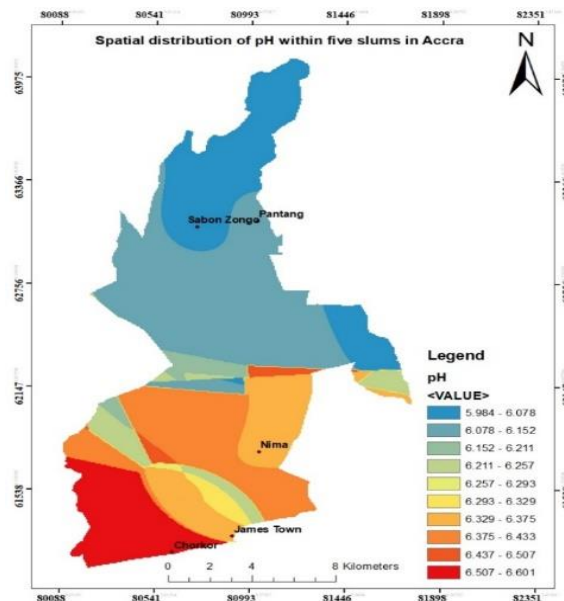
E. coli and total coliform of figures 4.47 and 4.48. E. coli is represented by Gaussian model while total coliform is represented by exponential model. The two parameters are relatively significant with total coliform having  $r^2$  values of 0.24 and E. coli 0.39. Even though the RSS values implies a less developed structure, the spatial variability suggest parameters can be sampled together.



**Figure 4.48: showing the variogram of Total Coliform**

#### 4.5 Geostatistical maps representing the spatial distribution of water quality parameters in the selected slums

The figure 4.49 and figure 4.50 below represent the mapping of pH and Turbidity in 5 slums within Accra. The pH is distributed across the 5 slums with the highest values recorded in the south which is mostly Chorkor, followed by Nima and Jamestown. The southern part of the map recorded low pH values in Sabon Zongo and Pantang. The water samples with lowest turbidity are within Sabon Zongo community and the most turbid water is found in Chorkor, Jamestown and Nima. Intermediate turbidity is located at the northern part which Pantang and Sabon Zongo. The southern part of the map is closer to the sea, and it could explain the high pH values due to the presence of numerous dissolved ions.



**Figure 4.49: showing pH distribution in selected slums**

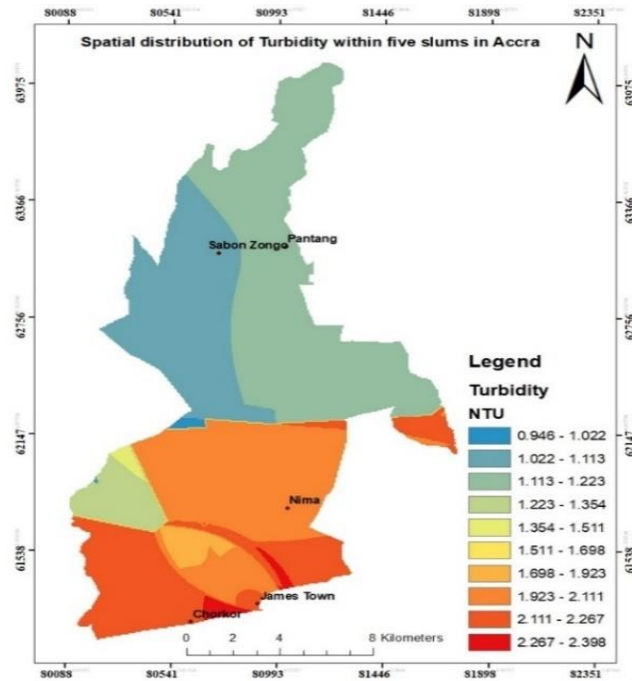


Figure 4.50: showing Turbidity distributions in selected slums

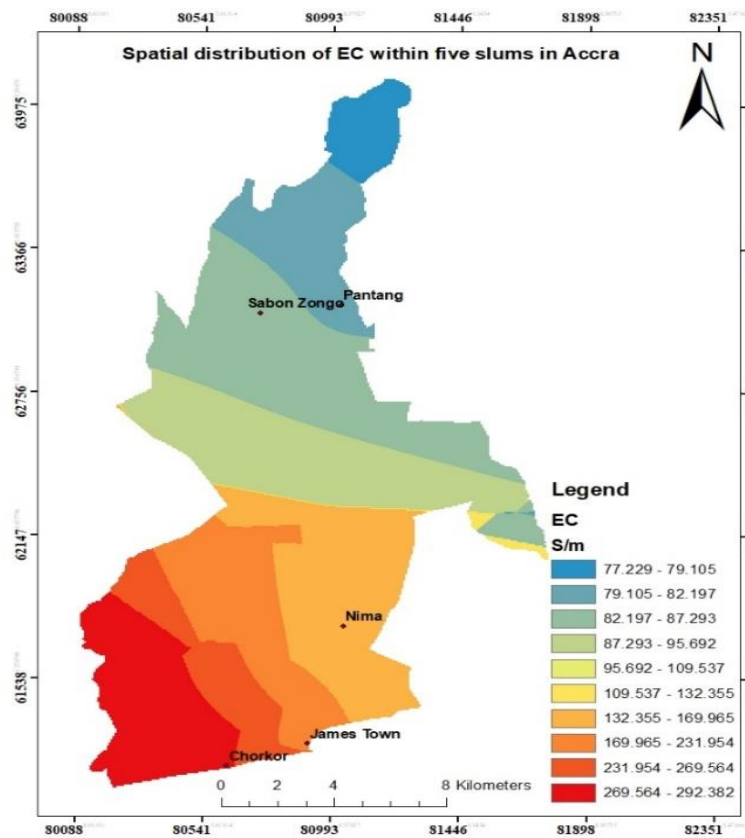
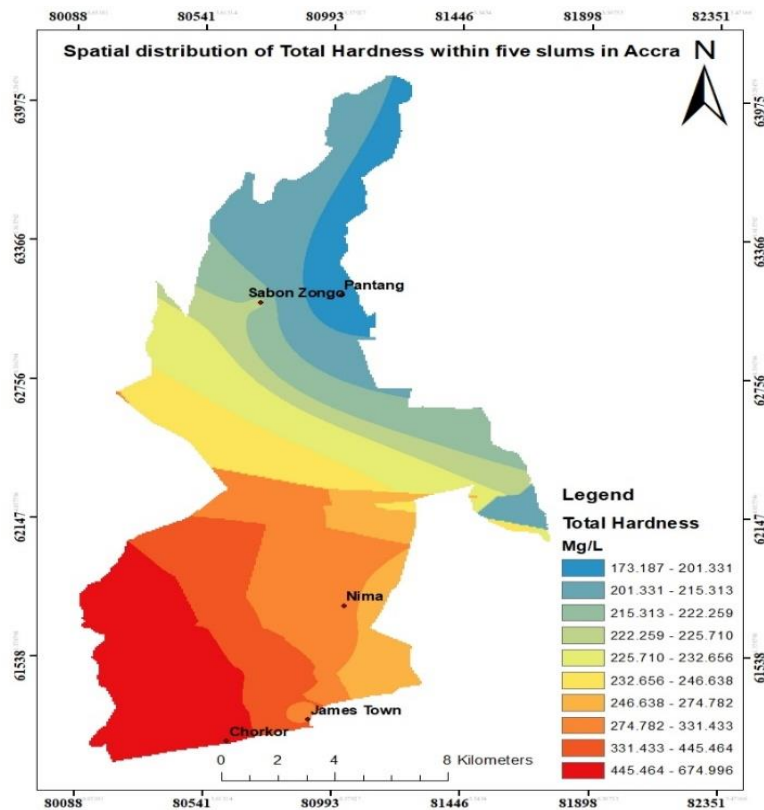


Figure 4.51: showing EC distribution in selected slums



**Figure 4.52: showing total hardness distribution in selected slums**

Figures 4.51 and 4.52 above represent the electrical conductivity distribution and total hardness. Electrical conductivity (EC) is an indicator of presence of dissolved ions and the highest is recorded in the southern slums such as Chorkor, Jamestown, and Nima. Intermediate EC concentration can be found at Sabon Zongo, and parts of Pantang. Pantang shows the lowest values of EC. Total hardness also follows the same trend of the lowest hardness in water samples collected in Pantang and Sabon Zongo which are located in the north and far away from the ocean. The southern part on the other hand shows high total hardness distribution which could be attributed to salt water intrusion from the sea as those southern slums are located on the Atlantic coast.



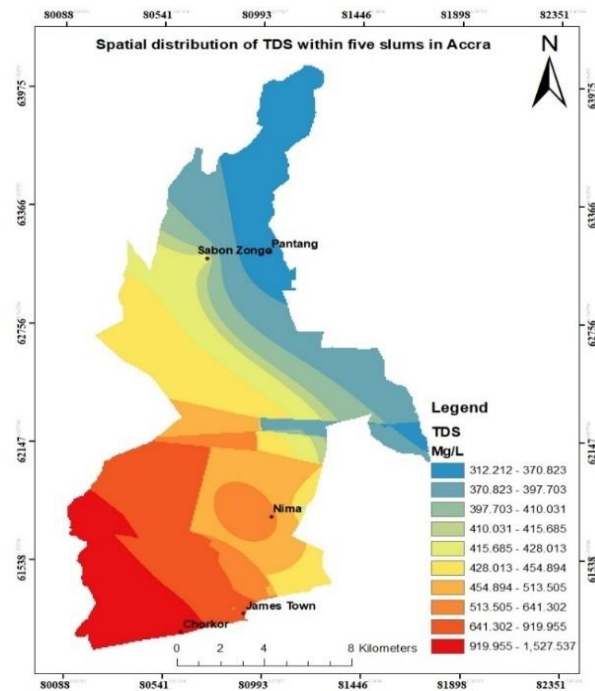


Figure 4.53 showing distribution of TDS in selected slums

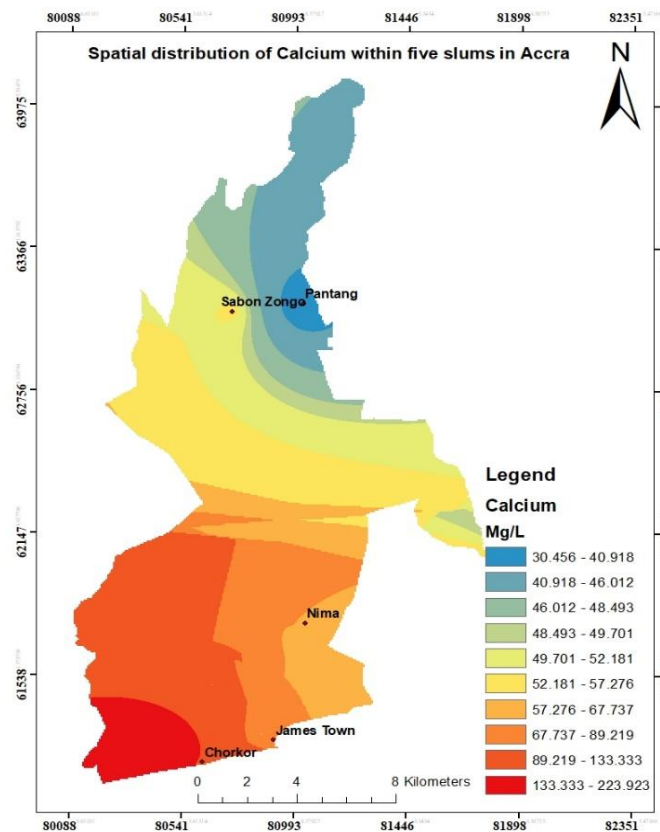
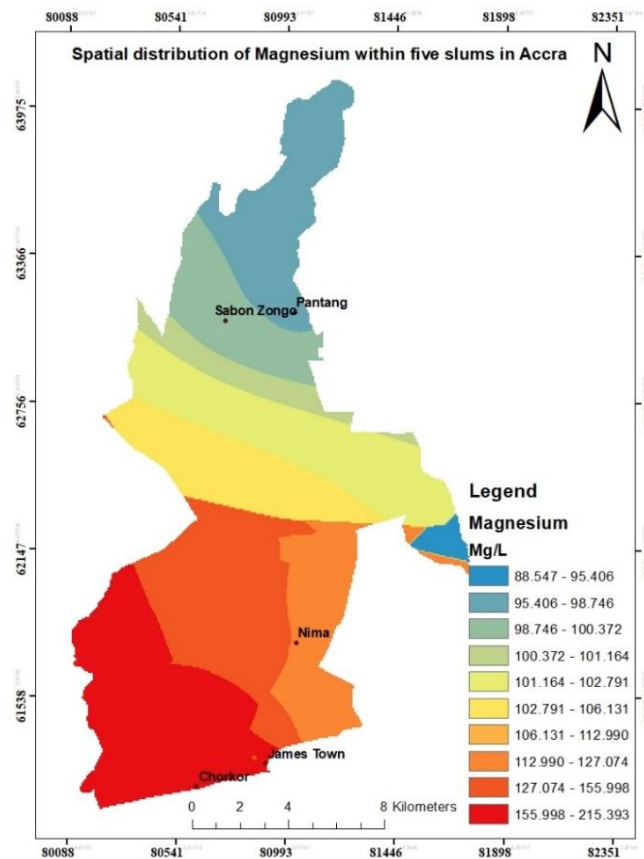
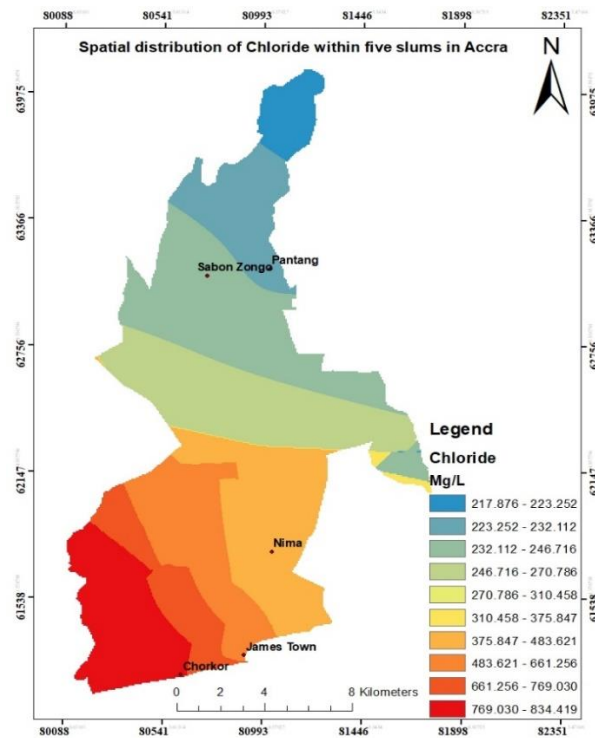


Figure 4.54: showing Calcium distribution in selected slums

The above figures of 4.53 and 4.54 represents Total dissolved solids (TDS) and calcium concentrations. In both parameters, the highest concentrations are distributed along the south which comprises of slums such as Chorkor, Jamestown, and Nima. Relatively high levels of the parameters are also distributed along the middle zone where Sabon Zongo is located. The lowest concentration of TDS and calcium are within the Pantang community. The maps of TDS and calcium shows similarities in constituent distribution because TDS is made of calcium ions as well. Also, the two parameters are both salt producing factors and their presence is interdependent.

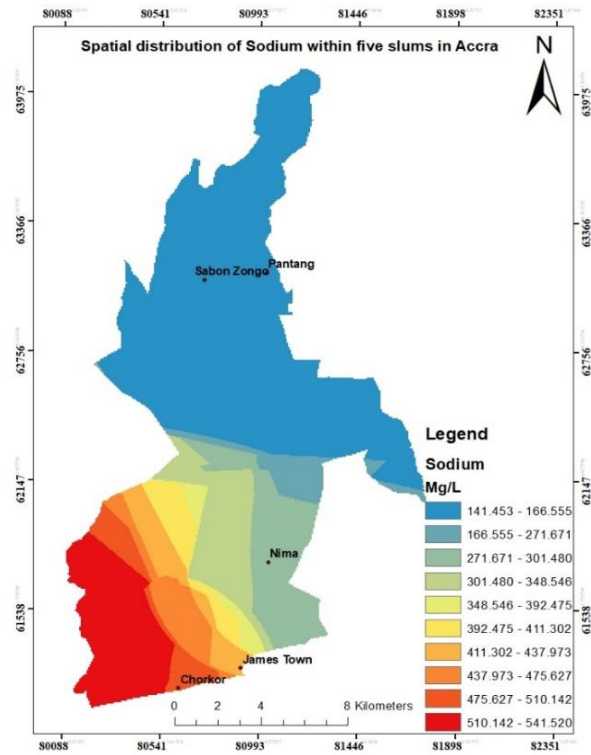


**Figure 4.55: showing Magnesium distribution in selected slums**

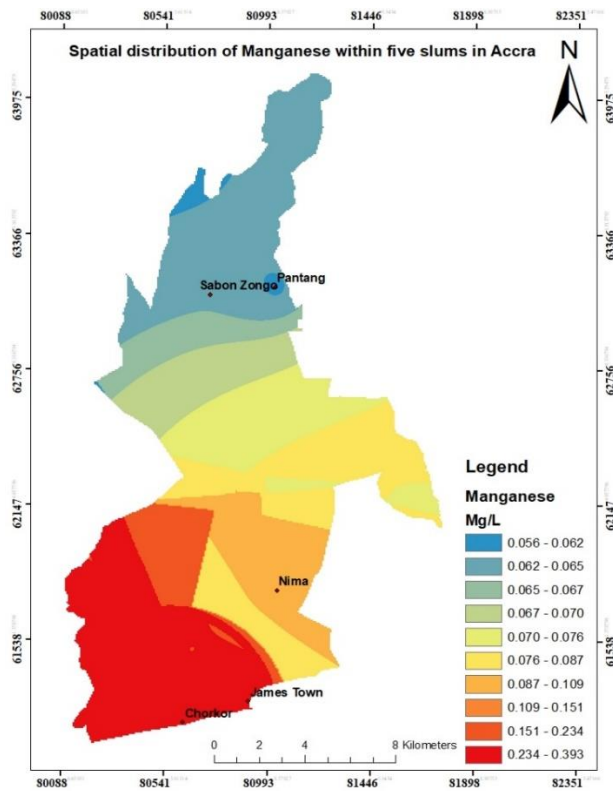


**Figure 4.56: showing Chloride distribution in selected slums**

The maps of figure 4.55 and 4.56 represents the spatial distribution of magnesium and chloride. The water quality parameter distribution shows that Pantang and Sabon Zongo have relatively low traces of chloride and magnesium compared to the southern part. The slum of Chorkor shows massive amounts of magnesium and chloride followed by Jamestown and Nima. The proximity of the southern slums to the sea could be responsible for the presence of the salt elements. Another possible contributing factor is the waste dumps and latrines located in the vicinity of the well locations.

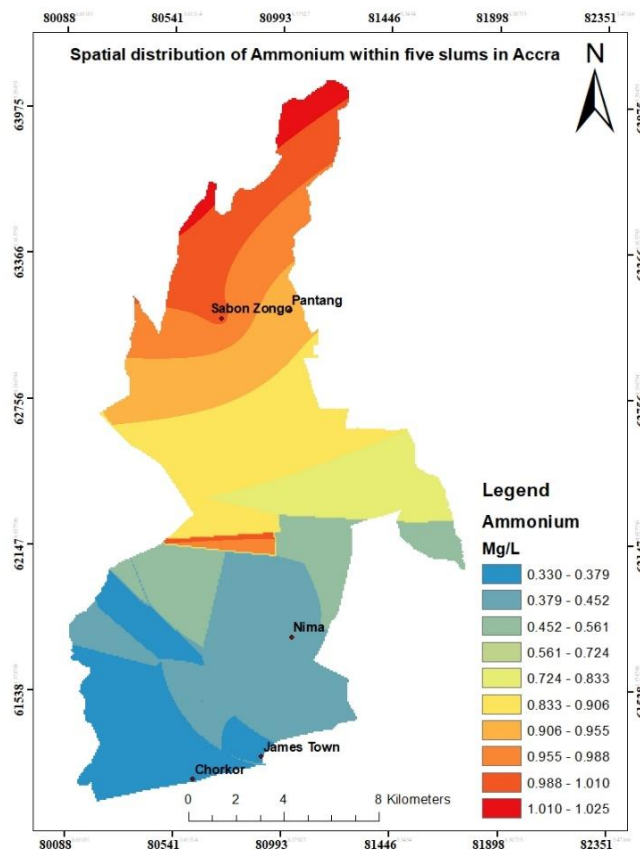


**Figure 4.57: showing distribution of Sodium in selected slum**

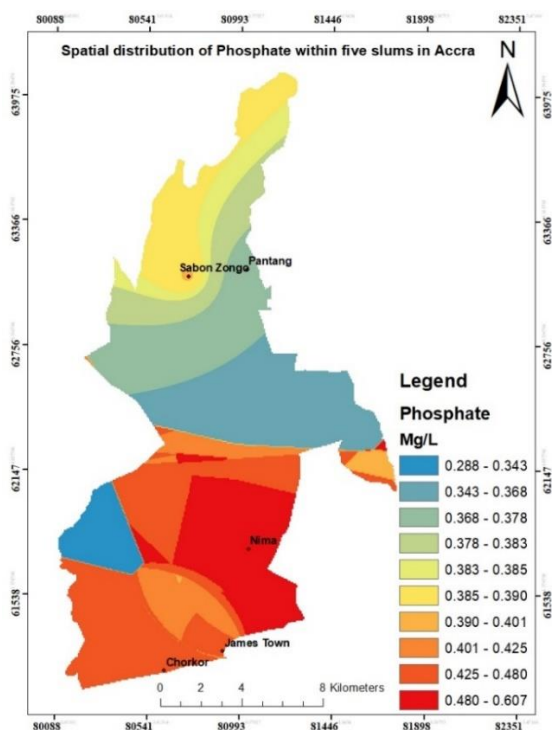


**Figure 4.58: showing the distribution of Manganese in selected slums**

Figure 4.57 and 4.58 shows the spatial distribution of sodium and manganese. The sodium distribution is very high in Chorkor with relatively high amounts in Jamestown and Nima. Parts of Jamestown and Nima also have intermediate concentrations of sodium. Low amount of the element is found in middle belt of Nima, the entire Sabon Zongo and Pantang. The Sodium distribution in the 5 slums could be attributed to geographical location of the slums and proximity to sewage systems and the ocean. Manganese is also distributed in the 5 slums with the lowest concentrations present in higher parts Pantang and Sabon Zongo. Within the middle zone of Pantang and Sabon Zongo, there are intermediate traces of the element. The entire Chorkor slum and parts of Jamestown is represented with abundance of manganese in the groundwater sources. Nima and Jamestown also shows relatively medium traces of the parameter. Presence of manganese in water is usually naturally occurring and amounts in groundwater increases with increasing residence time. That would explain the high amounts in Chorkor, Nima, and Jamestown as those slums are the oldest in Accra. Other contributing factors could be due to human activities such as improper solid waste dumps within the slums.

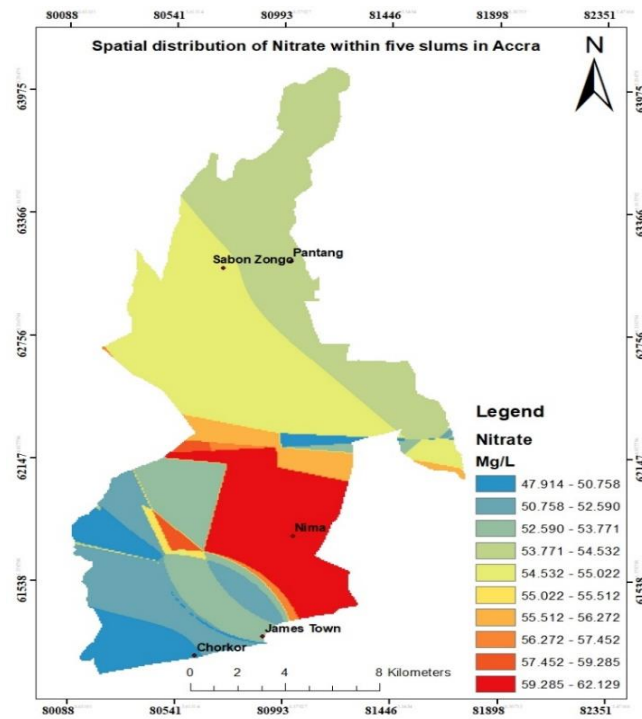


**Figure 4.59: showing the distribution of Ammonium in selected slum**

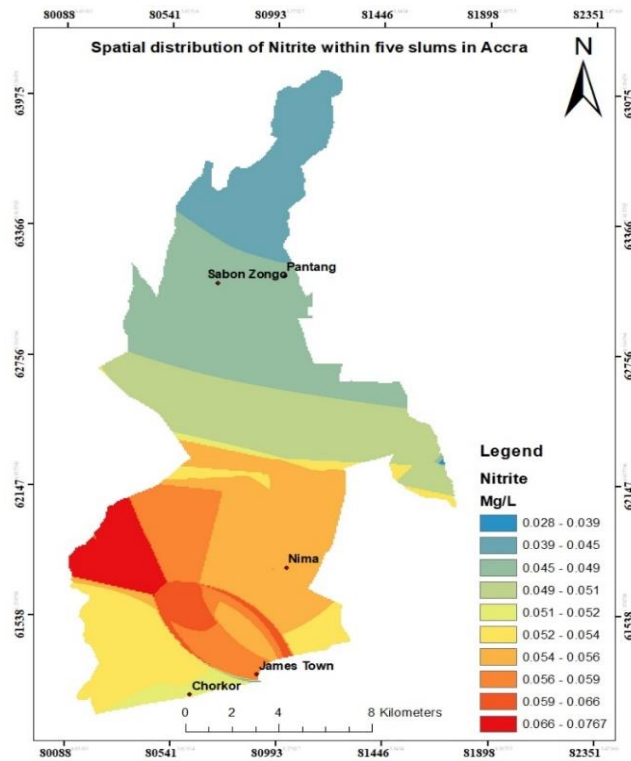


**Figure 4.60: showing phosphate distribution in selected slums**

The maps above show the distribution of Ammonium (figure 4.59) and Phosphate (figure 4.60) in the 5 slums of Accra. Ammonium concentrations are lowest in the slums at the southern zones and highest in the northern slums. Chorkor is the community with lowest level of ammonium and Pantang is the highest. The middle belt shows intermediate traces of the parameter. Pantang having the lowest concentration could be ascribed to the presence of the landfill in the community. The seepage from the dumpsite could be responsible for the high amounts. Phosphate on the other hand is very high in Nima followed by Chorkor and parts of Jamestown. Phosphate is introduced in groundwater through animal waste and fertilizers. Nima slum is known for cattle rearing. Greater parts of Pantang and Sabon Zongo shows minimal distribution of phosphate.

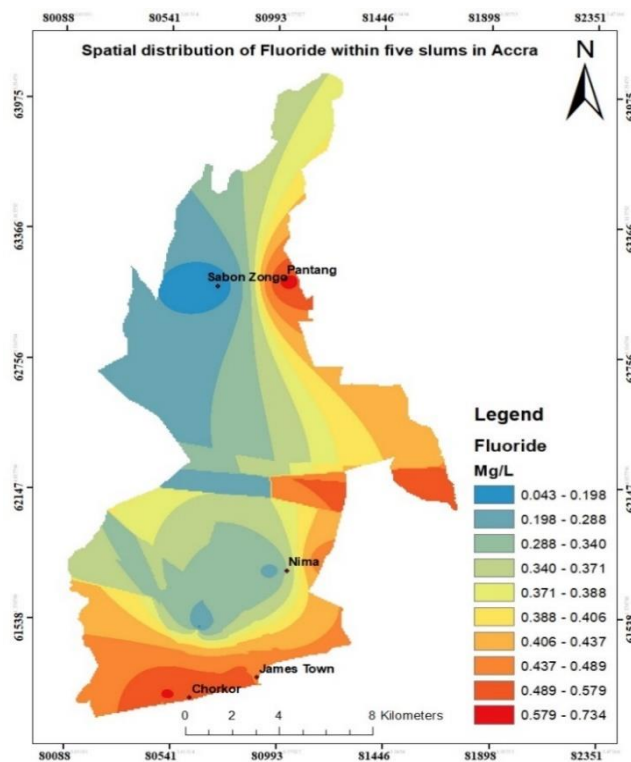


**Figure 4.61: showing the distribution of Nitrate in selected slums**



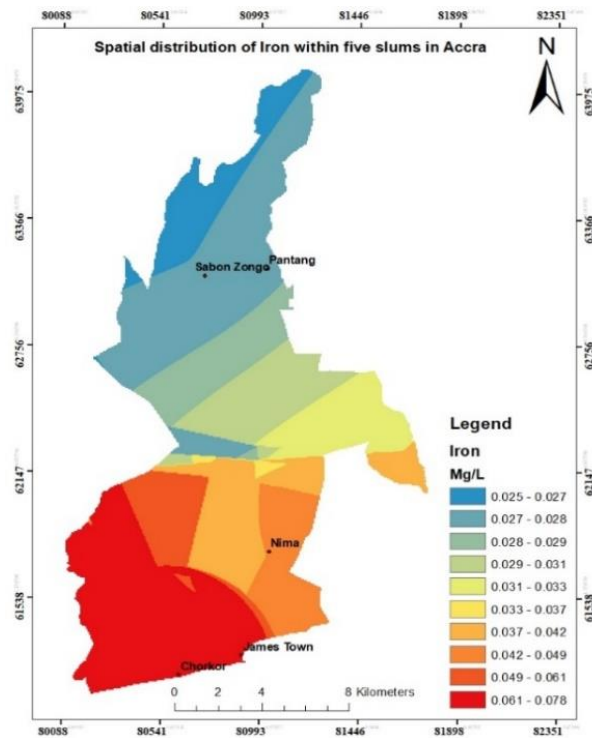
**Figure 4.62: showing the distribution of Nitrite in selected slums**

The above maps show the spatial distribution of Nitrate (figure 4.61) and Nitrite (4.62) in the slums under study. In figure 4.61, the lowest nitrate levels are located in Chorkor, and Jamestown with few sites of Jamestown showing high nitrate levels. The northern parts of the map show intermediate nitrate concentrations in Sabon Zongo and Pantang. The highest nitrate concentration is located at Nima. The Parameter could be introduced in the water through fertilizer application and animal waste. In the case of Nima, the nitrate could be as a result of cattle rearing which is common in the slum. The open drains and septic tanks could also cause leaching of nitrate into the water. Nitrite on the other had is evenly distributed across the slums with lowest in Pantang and Sabon Zongo. Traces of medium to high nitrite are also found in Jamestown and parts of Chorkor.



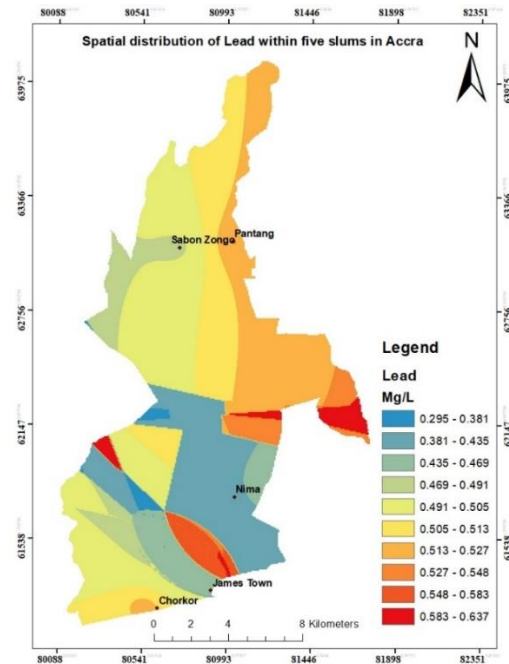
**Figure 4.63: showing Fluoride concentration in selected slums**



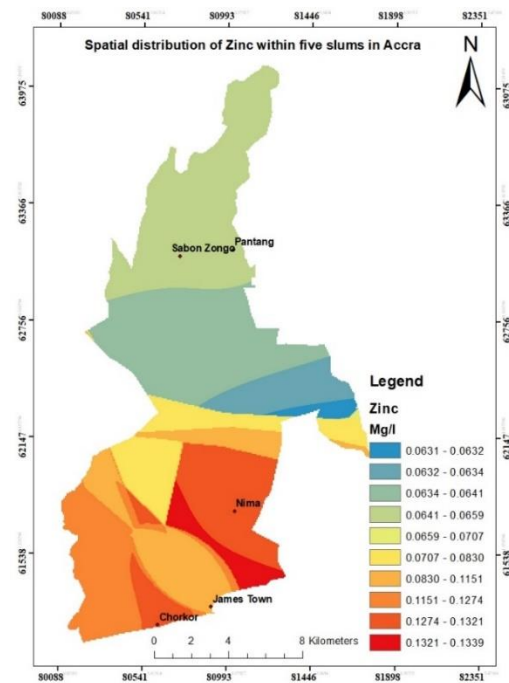


**Figure 4.64: showing Iron concentration in selected slums**

Figure 4.63 and figure 4.64 represents the spatial distribution of fluoride and iron. Fluoride is evenly distributed across all the slums in the study. Even though the concentrations were minimal, some slums show relatively higher concentrations than others. The lower parts of Chorkor, Nima, Jamestown, and Pantang have relatively high values. Lower concentrations were recorded in Sabon Zongo and the middle belt. Those areas with the relatively high fluoride levels are the ones high in other mineral contents and fluoride presence could be attributed to the presence of other dissolved ions. Iron concentration is high in the southern part of the map and low in the northern part. Pantang and Sabon Zongo are low in Iron concentrations.



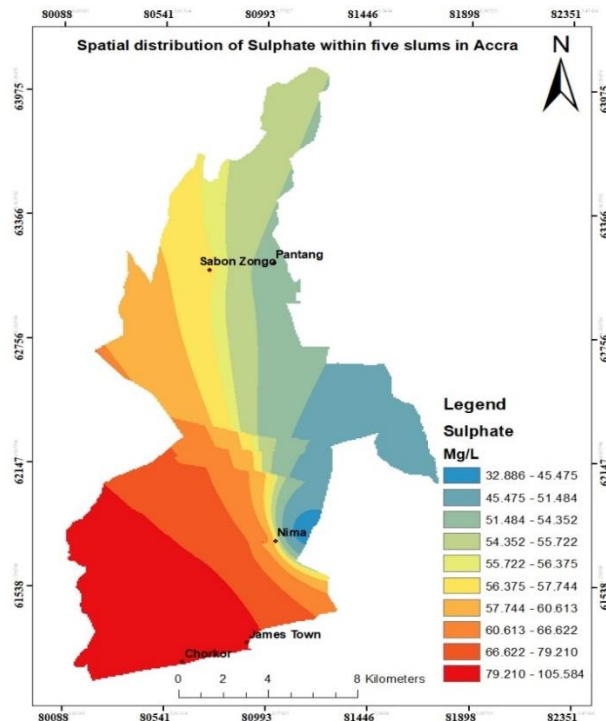
**Figure 4.65: showing Lead distribution in selected slums**



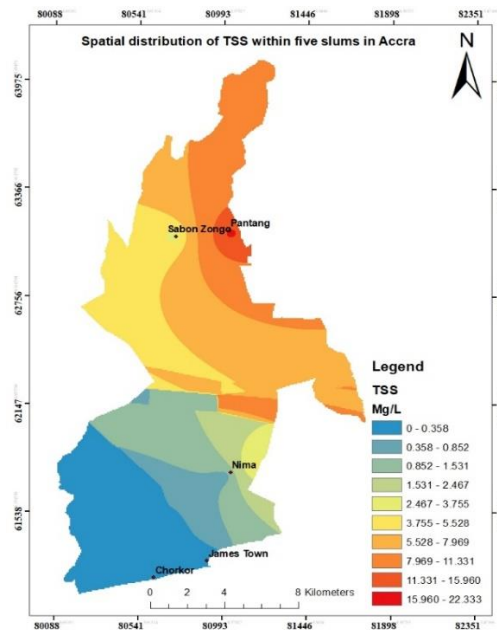
**Figure 4.66: showing Zinc concentration in selected slums**

The spatial distribution of lead and zinc is presented in figure 4.65 and figure 4.66. Lead is evenly distributed in the 5 slums of Accra. The highest concentrations are located in Pantang and Jamestown. Lead is introduced in groundwater through leachates from general waste and Pantang

houses a decomposing landfill site. That explains why lead concentrations are higher in that slum. Medium traces are also found in Sabon Zongo and parts of Chorkor. The lowest levels of lead are found in Nima community. The distribution of Zinc (figure 4.66) also shows two major divisions, the highest in the southern slums of the study map and the lowest amounts in the north. Nima has more Zinc in groundwaters followed by Jamestown and Chorkor. Zinc shows relatively minimal traces in all slums but the highest amount is recorded in Nima. This could be as result of seepage and burning of waste materials.

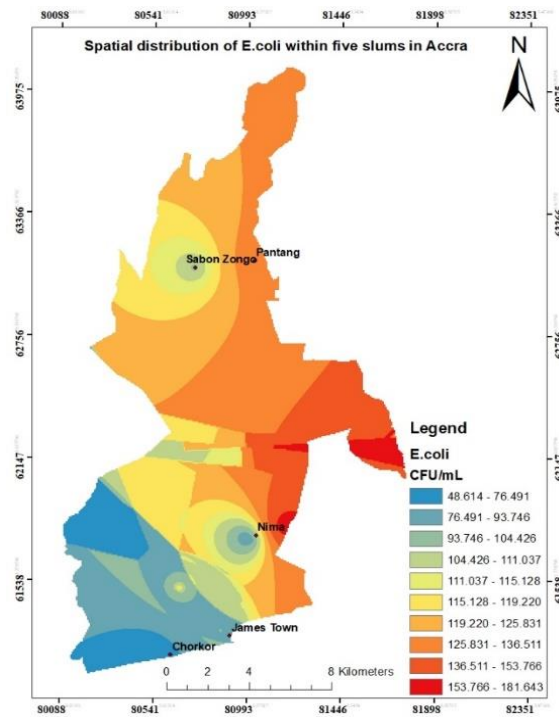


**Figure 4.67: showing Sulphate distribution in selected slum**

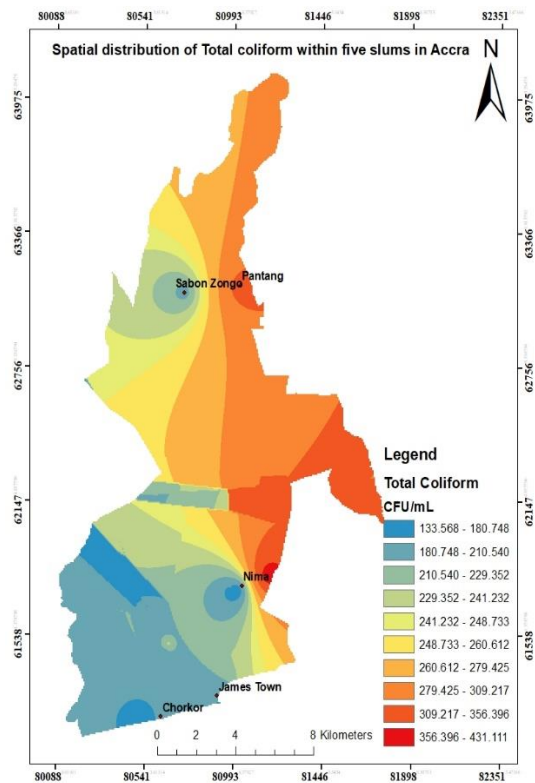


**Figure 4.68: Showing TSS distribution in selected slums**

Figure 4.67 and figure 4.68 are the distributions of sulphate and total suspended solids (TSS) in the 5 slums under study. The three (3) slums in the southern part of the study map holds the highest concentrations of other minerals and also high in sulphate. Sulphate can be present in groundwater that is high in magnesium and sodium and the southern area is one of them. Low levels of sulphate are present in parts of Nima and Pantang. The low to medium concentrations are also found in Sabon Zongo and parts of the middle belt. Total suspended solids (TSS) on the other hand is low in Chorkor, Jamestown and Nima. The groundwater sources from landfill slum (Pantang) are high in suspended solids. The high TSS in these communities could also be as result of the nature of the groundwater. Hand- dug wells are used in these communities and not completely protected from the atmosphere.



**Figure 4.69: showing E. coli distribution in selected slums**



**Figure 4.70: showing Total Coliform distribution in selected slums**

The coliform bacteria distribution in terms of *E. coli* (figure 4.69) and Total Coliform (figure 4.70) are represented in the maps above. Chorkor and Jamestown have the lowest concentrations of *E. coli*. The middle belt and the northern part of the study map which houses slums such as Nima, Sabon Zongo and Pantang are very high in *E. coli* bacteria counts. Bacteria is introduced in water through sewage leachate from latrine and dumpsites. Those slums have latrines in close range to groundwater sources and also decomposing landfills. The trend for *E. coli* distribution is the same for Total Coliform (TC) except for areas of Nima and Sabon Zongo that shows low levels of other coliform bacteria aside *E. coli*.

#### 4.8 Comparison between WHO and slum water parameters

Table 4.7: Showing WHO limits and Water quality parameters (values in red have exceeded the WHO limit in green)

Parameters	S.I Unit	WHO	Nima	Sabon Zongo	Chorkor	Jamestown	Pantang-Abokobi
pH		6.5-8.5	5.09	7.35	6.09	6.52	6.17
Turbidity	NTU	5.00	0.94	0.99	1.41	3.69	1.54
EC	µs/ m	150 .00	147.05	255.08	372.47	79.78	42.03
TDS	mg/L	1000.00	735.3	344.1	1862.4	398.5	210.1
Total Hardness	mg/L	500	292.50	400.00	717.50	215.00	167.50
Ca	mg/L	200 .00	150.00	222.50	462.50	155.00	110.00
Mg <sup>2+</sup>	mg/L	150.0	142.50	177.50	255.00	60.00	57.50
Cl <sup>-</sup>	mg/L	250 .00	416.60	727.3	1063.40	227.40	119.9
HCO <sup>3-</sup>	mg/L		62.22	191.62	100.04	91.50	77.47
Na	mg/L	200.00	270.37	472.00	690.16	147.60	77.85
Total Alkalinity	mg/L		51.00	196.00	82.00	75.00	63.50
F	mg/L	1.50	0.20	0.18	0.54	0.56	0.59
K	mg/L		28.10	48.53	27.45	60.18	15.85
Fe	mg/L	0.30	0.03	0.02	0.13	0.05	0.05
S	mg/L	250 .00	60.50	85.25	87.75	91.00	39.25

<b>Mn</b>	mg/L	0.10	0.11	0.02	0.73	0.05	0.12
<b>NO<sup>3-</sup></b>	mg/L	50.00	67.43	54.12	27.06	73.48	36.41
<b>NO<sup>2-</sup></b>	mg/L	3.00	0.06	0.07	0.06	0.00	0.00
<b>Pb</b>	mg/L	0.01	0.25	0.00	1.00	0.25	1.50
<b>NH<sup>4+</sup></b>	mg/L	1.50	1.31	0.31	0.56	0.11	0.78
<b>PO<sub>4</sub><sup>3-</sup></b>	mg/L	30.00	0.29	0.64	0.12	0.97	0.17
<b>As</b>	mg/L	0.01	0	0	0	0	0
<b>Zn</b>	mg/L	3.00	0.05	0.11	0.02	0.34	0.06
<b>TSS</b>	mg/L	0.00	0.25	0.00	0.00	0.00	12.50
<b>E. coli</b>	CFU/100mL	0.00	18.25	149.75	12.50	89.50	249.00
<b>Total Coliform</b>	CFU/100mL	0.00	90.75	237.75	162.75	185.25	490.25

#### 4.8.2 Physical parameters in comparison with WHO standards

The physical parameters in this case consists of pH, turbidity, electrical conductivity and total hardness. pH values recorded within the different slums range between 5.09 to 6.52. The lowest pH values were recorded within Nima community. Nima, Sabon Zongo, Chorkor, Jamestown and Pantang recorded average pH values of 5.09, 7.35, 6.09, 6.52 and 6.17. All the values fell within the WHO pH range of 6.5-8.5 except that of Nima, Chorkor and Pantang. Turbidity values in the five slums are 0.94, 0.98, 1.41, 3.68 and 1.54 NTU. All the turbidity values are below the standard value of 5.00NTU. Nima recorded the lowest turbidity value and Jamestown had the maximum all within the WHO value. The average electrical conductivity recorded in the twenty samples has a mean value of 172  $\mu$ S/m. The recorded mean values per slum states as 147.05 $\mu$ S/m, 255.08 $\mu$ S/m, 372.7 $\mu$ S/m, 79.78 $\mu$ S/m, 32.03 $\mu$ S/m for Nima, Sabon Zongo, Chorkor, Jamestown and Pantang respectively. The WHO standard for EC is 150 $\mu$ S/m and slum 2 and 3 have exceeded the limit. The average total hardness per slum are 292.50mg/L, 400.00 mg/L, 717.50 mg/L, 215.00 mg/L and 167.50 mg/L. All slums recorded mean values below the WHO limit except for slum 3 which exceeded the 500mg/L by recording 717.50 mg/L.

### 4.8.3 Chemical parameters in Comparison with WHO standards

#### *Cations*

The cations measured during the study include calcium, magnesium, potassium, sodium, ammonium and manganese. The mean calcium concentrations in the various slum are 150.00 mg/L, 222.50 mg/L, 462.50 mg/L, 155.00 mg/L, and 110.00mg/L for slums 1, 2, 3, 4, and 5 respectively. The calcium concentrations in slum 2 and 3 have exceeded the WHO standard of 200mg/L. In terms of magnesium levels in the groundwater, slum 1, 2, 3, 4 and 5 produced concentrations of 142.50 mg/L, 177.50 mg/L, 255.00 mg/L, 60.00 mg/L and 57.50mg/L respectively. Slums 1, 4 and 5 have concentrations within the WHO standard but slum 2 and 3 have exceeded the limit of 150mg/L with magnesium concentrations of 177.50mg/L and 255.00mg/L. Three out the five slums studied for sodium concentration have average values beyond the WHO value of 200mg/L. The mean sodium concentrations per slum are 270.37 mg/L, 472.00 mg/L, 690.16 mg/L, 147.16 mg/L and 77.85 mg/L respectively for slum 1 to 5. Ammonium levels in all the twenty samples within the five selected slums are below the WHO standard value of 1.50mg/L. The mean ammonium concentrations are 1.31 mg/L, 0.31 mg/L, 0.55 mg/L, and 0.11 mg/L, 0.78mg/L for slum 1, 2, 3, 4, and 5. Manganese concentration was detected in a water samples from all the slums with slum 1, 3 and 5 exceeding the 0.10 mg/L permissible limit. The concentrations observed shows 0.11 mg/L, 0.02 mg/L, 0.73 mg/L, 0.05 mg/L and 0.12mg/L respectively. Slums 2 and 4 have Manganese concentrations within the WHO range.

#### *Anions*

The water quality anions studied are chloride fluoride, phosphate, sulphate, nitrate, nitrite and bicarbonate. Fluoride concentrations in the sampled water was relatively minimal with all slums having mean values below the 1.50mg/L permissible value of WHO. The average fluoride values per slum indicates 0.20 mg/L, 0.17 mg/L, 0.54 mg/L, 0.55 mg/L, and 0.59mg/L for slum 1, 2, 3, 4 and 5 respectively. In terms of chloride concentrations, the WHO standard value is 250mg/L but the case is different for slum 1, 2 and 3 as these slums have recorded the very high chloride concentrations such as 416.6 mg/L, 727.3 mg/L and 1063.4mg/L respectively. The rest of the two slums have average chloride levels of 227.4mg/L and 119mg/L which are below the acceptable value. The WHO limit for Phosphate is 30mg/L but all the groundwater samples analyzed indicated very minimal concentrations far below the standard limit. Slums 1, 2, 3, 4, and 5 showed Phosphate concentrations of 0.29 mg/L, 0.64 mg/L, 0.11 mg/L, 0.97 mg/L and 0.17mg/L respectively. Slums



1 to 5 recorded Sulphate values of 60.50 mg/L, 85.25 mg/L, 87.75 mg/L, 91.00 mg/L, 39.25mg/L respectively. The standard limit for sulphate concentrations in drinking water is 250mg/L. All of the slums show Sulphate values below the acceptable value. The Nitrate limit according to WHO is 50mg/L. High levels of Nitrate were recorded in slum 1, 2 and 4 with the concentrations of 67.43mg/L, 54.12mg/L, and 73.48mg/L respectively. The rest of the slums which is slums 3 and 5 indicates low average nitrate values of 27.06 mg/L and 36.41mg/L which is below the standard limit. The reduced nitrogen concentration (Nitrite) were extremely minimal with average concentrations of 0.06 mg/L, 0.07 mg/L, 0.06 mg/L, 0.005 mg/L, and 0.008 mg/L in slums 1 to 5 respectively. All of the nitrite concentrations were below the WHO limit of 3.00mg/L. Bicarbonate does not have any health implications according to WHO but the samples recorded concentrations such as 62.22 mg/L, 191.62 mg/L, 100.04 mg/L, 91.50 mg/L and 77.47mg/L for slums 1 to 5 accordingly.

### ***Heavy metals***

The heavy metals measured in this study consists of lead and arsenic. The WHO standard for lead is 0.01mg/L and four slums among the 5 have exceeded the standard limit. The Lead concentrations in slum 1 to 5 are 0.25 mg/L, 0.00 mg/L, 1.00 mg/L, 0.25 mg/L and 1.50mg/L respectively. Slum 1, 3, 4 and 5 showed high presence of lead in the water which is above the permissible limit. Slum 2 recorded 0.00 traces of Lead. No Arsenic content was detected in all of the twenty samples of water.

### ***Trace Elements***

Two trace elements were measured during the laboratory analysis of water samples. This includes: Iron and zinc

Iron concentrations in the groundwater were below the WHO standard value of 0.30mg/L. Slums 1 to 5 recorded Iron concentrations of 0.03 mg/L, 0.02 mg/L, 0.13 mg/L, 0.04 mg/L, 0.05mg/L correspondingly. The zinc average values per slum are 0.05 mg/L, 0.11 mg/L, 0.03 mg/L, 0.34, mg/L and 0.06 mg/L for slum 1, 2, 3, 4, and 5 respectively. All the average Zinc values are below the permissible standard of 3.00mg/L.

#### ***4.8.4 Bacteriological water quality Indicators in comparison with WHO standards***

E. coli and total coliform were the two bacteriological indicators used for the groundwater quality check. The WHO standard for bacterial contamination states that for every 100ml of water sample should contain zero (0) coliform. All the water samples showed presence of E. coli and other forms

of coliform bacteria in high quantities which are above the permissible standard. The average E. coli values per slum are 18.25 CFU/100ml, 149.75 CFU/100ml, 12.50 CFU/100ml, 89.50 CFU/100ml, 249.00 CFU/100ml for slum 1 to 5 respectively. The mean total coliform counted per slum are 90.75 CFU/100ml, 237.75 CFU/100ml, 162.75 CFU/100ml, 185.25 CFU/100ml and 490.25 CFU/100ml per sample for slum 1, 2, 3, 4 and 5 respectively.

#### **4.9 State of Groundwater use in the five selected slums (Field survey)**

##### **4.9.1 Nima (slum 1)**

The water sampled from Nima community was a mixture of boreholes and hand-dug well. The groundwater sources have been in existence for twenty-one years (21), twelve years (12), twelve (12) years, five(years) respectively for sample 1, 2, 3 and 4. Sample one was a borehole that is not shared with neighbours but it used for cooking, bathing and washing. The owner of the borehole has not checked the quality before because according to him there was no need for quality check. The borehole is located in less than 50 metres for a rubbish dump and public toilet at the same place. Sample two is mainly used for washing but sold to neighbours that use it for domestic purposes which were not accounted for. The owner has conducted a quality check once during the 12 years of existence and last quality check was between 4-5 years before sampling. The third sample is also shared with other people in the community and used for all purposes in cases where municipal water is unavailable. The owner of the borehole indicated there was no need to run quality analysis on the water because it is known that water from the ground is clean. Sample number four from the community was a dug well that is shared with people for domestic purposes but only when there is a cut off in municipal pipe water. The water does not have any landfill in close range but a public latrine within less than 50 metres.

##### **4.9.2 Sabon Zongo (Slum 2)**

Sabon Zongo is a slum community which samples were taken from hand- dug wells. Sample one is shared with people in event of municipal water cut-off. The water is used for cooking, ablution, bathing and occasional drinking. It has been in use for more than 10 years. Sample two is located behind household pit latrine and also used for ablution, cooking and bathing. The well water is shared with neighbours for domestic purposes only. The third sample from the slum is located about 10 feet away from a public septic tank. It is used and shared with others for washing, cooking and

bathing. A small rubbish dump is located about 100 metres from the well. The owner explained he has not conducted a quality check during the existence of the well but looking forward to it in the future. The last sample from the community is located at the road side and shares boundary with a drainage gutter. A pit latrine is located right beside the well. No quality test has been conducted on the water as at the time of sampling. The well has been in use for more than five years. A verbal interview was conducted with one of the neighbours who use the well water, and she confirmed the use of the water for all water uses.

#### **4.9.3 Chorkor (Slum 3)**

Chorkor community uses boreholes as a source of groundwater. Hundred percent of water sampled was situated in the premises of a latrine used by the public. The source of water is sold to neighbors for domestic uses. Even though the interview results showed that the indigenes do not use the water for drinking always, but admit to using for cooking and ablution. Fifty percent of the samples were located in less than 30metres to rubbish dump on the shore of the Atlantic sea. According to the people, they have not noticed any change in the water during the period of usage hence sees no reason to conduct quality test. The boreholes have been in existence for seven (7) years for, twenty(years), four (4) and ten (10) for sample number one to four respectively.

#### **4.9.4 Jamestown (Slum 4)**

All the water sampled in Jamestown were hand- dug wells. Sample number one, two, and three has been in existence for more than a century. Sample number one is used for all purposes including drinking and the water is just a few metres away from a squat public toilet. The water is sold to people for domestic purposes. The owner of the well has not the checked the quality of the water because he has knowledge on how to conduct water quality test. Sample number two (2) is situated in less than hundred metres from a major landfill which was closed down not long before the time of sampling. Sample three (3) is also used for drinking and other domestic purposes. The sample source is in a vicinity of a rubbish dump. The last sample in the community is shared with neighbours and it is used for all purposes including drinking and Ablution. Sample number four has been in existence for twelve years which is different from the rest of the slum samples in terms of period of usage.

#### **4.9.5 Pantang-Abokobi (Slum 5)**

Pantang- Abokobi is a developing neighborhood which is located around the biggest landfill in Accra. Even though the landfill does not receive new waste, the old one is still piled on acres of land and decomposing. The populace use hand-dug wells except for those who can afford the municipal treated water sold in tankers. Sample number one was a hand-dug well for household uses which includes drinking, washing, cooking and bathing. The dug well has been in existence for three (3) years and it is located about 20 metres from a pit latrine (squat). The well is also in the locality of a local soap making factory. The second sample from the community has also been in existence for 5 years and it is used for all purposes except drinking and the well location is about 10 metres from the land harbouring the decomposing landfill. Sample number three is main source of drinking water for the users in the house and the water is shared with neighbours. The well is covered with iron sheet and the house uses pit latrine that is within 15 metres away from the well. The well has been in existence for three years. The last sample from the community is also used by neighbours for Washing, cooking and, bathing. It has been in use for five years. All the people interviewed stated the quality of the water has not been checked during the period of usage.

#### **4.10 Extent of Physicochemical Contamination and Health implication**

The pH of the samples in slum 1 was typically acidic. The pH values were as low 3.7 and the maximum pH value in the slum was 6.51 which is within the accepted range. The low pH value could be attributed to the presence of small rubbish dumps and the major drainage gutters passing through the slum. pH results from slum two were relatively high compared to the other slums. The recorded basic pH values render the implication of the high alkaline crust systems and also the emanating from sewage water seepage. The acidity of the water in slum 3 is averagely acid with one sample neutral. Slum 4 and 5 also produced acidic pH. In all, the low pH is as result of the bad sanitation in the area and the close proximity to sewage systems. Consumption of acidic water could make water taste sour and metallic but there is no confirmed health concern for pH but it is advisable to drink water of pH within the WHO range of 6.5 and 8.5 (Culligan water, 2019).

Turbidity values from all of the slums are below the WHO permissible value of 5NTU.

Electrical conductivity is the measure of the number of dissolved chemicals, inorganic chemicals and ions that are present in the water. The amount of salt indicates the level of total dissolved solids in the water. The study showed that the electrical conductivity of slum 2 and slum 3 are above the

WHO value of 150mg/L. This implies those slums have higher number of dissolved ions present in the water. The TDS of slum 3 is above the limit of 1000mg/L indicating higher level of dissolved ions. The high TDS level (1862.4mg/L) in slum 3 could be as a result of the coast where the slum is situated. Salt water intrusion from the sea could be the major contributing factor. Even though slum 2 has a mean electrical conductivity above the limit, its TDS is within the permissible range. Slum 2 and 3 have high levels of salts (chloride, sodium, calcium and magnesium) that make up the TDS in high quantities above the WHO limit. The high level of chloride, sodium calcium and magnesium in slum 3 could explain the reason why the slum recorded the highest total dissolved solids. The total hardness, calcium, chloride, magnesium and sodium of slum 2 and 3 have exceeded the WHO standard values of 500mg/L, 200mg/L, 150mg/L and 200mg/L respectively. Even though total hardness of slum 2 produced a borderline value, the other salts exceeded their limit thereby resulting in the increased level of dissolved ions. The salts that have exceeded the standard limit are all in slum 2 and 3 but slum 1 recorded 416.6mg/L Chloride and 270.37mg/L of sodium which has exceeded 250mg/L and 200mg/L limit respectively. The rest of the slums have their EC, TDS, calcium, Magnesium, Chloride, and Sodium within acceptable standard. The people who drink this type of groundwater in slum 3 and 2 are at the risk of experiencing dehydration, less circulation of blood and organ failure (kidney). High salt consumption makes one urinate more that they produce fluids thereby increasing dehydration and eventually death (NOAA, 2018).

The fluoride concentration in the groundwater within the five selected slums are relatively minimal and below the WHO value of 1.5mg/L. The consumption of low-level fluoride water can help prevent dental caries (WHO, World health organization, 2019).

The amounts of Iron found in the samples are below the WHO accepted value of 0.30mg/L. All the Twenty samples from five different slums produced relatively minimal traces of iron.

Sulphate, ammonium, potassium and phosphate elements were all within the permissible range of the World health Organization in both the mean of parameters per slum and the individual sample measurements.

Manganese concentrations were higher than the WHO limit (0.10mg/L) in slums 1, 3 and 5. Manganese is introduced to groundwater through sewage, use of manganese insecticides and direct exposure from the atmosphere. In the frame of this study, the relatively high levels of the manganese could be as a result of sitting of boreholes close to latrines and the major landfills specifically for slum 5. The element is a toxic parameter which at small concentrations causes

damage. Consumption of high levels of Manganese is detrimental to health as it causes respiratory tract damage, brain disorder with associated signs of hallucination, nerve damage and lung problems. Studies have also confirmed, men who consume manganese for a long period of time could be at the risk of becoming impotent (LENNTECH, Manganese, 2019).

The standard value for lead in drinking water is 0.01mg/L but the case is different for the four out of five slums under study as they recorded relatively high amounts of lead in the water samples. Slums 1, 3, 4 and 5 showed mean lead concentrations of 0.25, 1.00, 0.25 and 1.5 mg/L respectively. Lead is one of the ten major chemicals of public concern on WHO red list and exposure to small amount is dangerous to human health. Lead can be found in car batteries, paints and some household appliances. The high level of the lead in the water samples could be attributed to the landfills as it contains waste from diverse sources. Slum 5 is the area harbouring the largest decomposing landfill in Accra and slum 5 recorded the highest concentration of lead (1.5mg/L). 75% of the water sampled from slum 5 is used for drinking purposes. Two out of the four samples from slum 1 also serve for drinking while samples from slum 4 are also used for drinking. People who drink water containing lead are at the risk of getting lead poisoning. Lead poisoning has dangerous health consequences especially in children, pregnant women and general human health. Lead being radioactive causes kidney damage, high blood pressure and miscarriage in pregnant women (WHO, World health organization, 2019). There are other health effects on children experiencing lead poisoning which can lead to disrupt in learning capacities of children, behavioral changes such as aggression and hyperactivity (LENNTECH, 2019).

No traces of Arsenic were found any of the groundwater samples analyzed.

All the mean values of Zinc concentration the water is below the WHO standard value.

The acceptable standard of Nitrate in drinking water is 50mg/L and that of Nitrite is 3.00mg/L. The nitrate concentration in slums 1, 2, and 4 are 67.430mg/L, 54.120mg/L and 73.480mg/L respectively. The rest of the two slums produced nitrate concentrations below the acceptable value. Jamestown (slum 5) showed the highest concentrations of nitrate followed by slum 1 and finally slum 2. Nitrate is introduced in water through uncontrolled sewage leaching, fertilizer application and car exhaust and general refuse dump leakage. Slum 1 has unsanitary sewage management system coupled with cattle rearing and that could account for the rise in the nitrate concentration. Some areas of slum 2 engage in cabbage and lettuce farming which requires lots fertilizer and other nitrogen containing compounds. Also, slum 2 has all of their wells in the same place as the public

toilet and the septic tank. The nitrate could have entered the well through an underground leaching from the tank. Slum 4 holds the highest concentration of nitrates. Slum 4 is the oldest community in Accra from the 17<sup>th</sup> century and a fishing community. The wells in that slum are centuries old and nitrate concentration could be attributed to the diverse activities which include chemicals used in fishing, solid waste, sewage, cattle rearing. Most samples from these three slums serve as drinking water for some households. The survey pointed out that groundwater from slum 1, 2, and 4 serve for cooking purposes and nitrate cannot be removed by boiling the water and this implies cooking with nitrate contaminated water produces same effect as direct drinking (Robert L. Manhler, 2007). Consumption of water containing nitrate produces massive health consequences. Nitrate in water combine with amides and amines to form N-Nitroso compounds which are known to cause cancer in humans. The prominent health impacts on humans is Methaemoglobinaemia which prevents oxygen circulation in the body to the tissues. The reduced oxygen circulation causes the body cyanosis in infants below three (3) months and pregnant women (WHO, 2016). The reduced nitrogen compound in all the slums are below the acceptable value of 3.00mg/L.

TSS standard limit from WHO is 0.00mg/L but slums 1 and 5 have recorded values exceeding the acceptable range. Slum 1 had a mean TSS value of 0.25mg/L and slum 5 indicated a relatively high TSS value of 12.50mg/L. Drinking of water with presence of suspended particles could be unpleasant to consumers. Total suspended particles cause decrease in the amount oxygen present in the water and also activates temperature rise (Center, 2019). The high TSS in slum 5 could be originating from seepage from the decomposing matter from the abandoned landfill. Another possible contributing factor is the fact that the groundwater sources were hand-dug and not properly protected from the particles from the atmosphere.

#### **4.11 Extent of Microbial contamination and Health implication**

The bacteriological indicators used for water quality check in this study are *Escherichia coli* (*E. coli*), a coliform bacteria and total Coliform. The WHO standard for bacterial contamination is 0.00mL which implies for every 100ml of water, there should be zero bacteria (WHO, 2017). All the *E. coli* and total coliform counts have exceeded the WHO accepted value. *E. coli* is an indicator organism for the presence of any other bacteria and faecal contamination in water. The faecal coliform bacteria could be introduced in the water as a result of the siting of the well. Most of the wells especially those in slum 3 and 5 are situated few metres away from a pit latrine and

refuse dumps specifically for slum 5. The movement of bacteria into the water could be as a result of faeces leakage into the well. Water sampled from hand dug-wells were incompletely covered with either a wooden board or pieces of iron sheets. External contamination from the atmosphere could also introduce bacteria into the water due to lack of well protection. *E. coli* is found in the environment, food, water, and the intestine of humans. Among them are some harmful bacteria which causes illness of different types when consumed. Drinking water containing coliform bacteria may bring diarrhea, pneumonia, urinary tract infections and respiratory problems (CDC, 2019). The total coliforms could also contain other coliform bacteria such as *vibrio cholerae* which can cause Cholera among people. Cholera outbreak is very rampant in Accra.

#### **4.12 Slum Livelihood and Groundwater use**

Among the twenty samples from the five different slums, only one owner has conducted a quality check once during twelve-year usage. 65% of the samples were hand-dug wells and 35 % were drilled- boreholes with a tap. 90% of the samples from the slums are shared with neighbours at a cost. The water is used for all domestic purposes with 50% percent used for drinking. The groundwater is shared with neighbours even though there is little or no quality check. Majority of the groundwater in the various slums are very close to improper toilet facilities. Sanitation conditions of the people is extremely bad which puts the population at a health risk. The slums in a vicinity of a landfill have the highest bacterial contamination and lead poisoning. Per the results of the laboratory analysis, the people are consuming contaminated water and in danger of contacting diseases of short- and long-term effects. There is high level of salt in slum 3 and intake of excessive salt water for a long period of time causes heart related issues. Only slum 5 is lacking municipal water coverage and the rest are connected. Despite the presence of treated water network in some slums, the people still depend on groundwater because of the inconsistencies in the flow the municipal treated water. About 60% of the people in the slums stated they only use the groundwater when there is cut off in the flow of the pipe water and it happens often. Some also stated that they cannot afford the municipal water and well water is a cheaper option. All the hand-dug wells sampled were improperly protected from contamination from the atmosphere. The wells were either covered half way with a wooden board or pieces of Iron sheet. The implication is that there could be possible contamination from the atmosphere. The government conducts one-time quality check on boreholes drilled by licensed private companies as part of license requirement.



There is no monitoring check after that and the people continue selling the water to the less endowed indigenous of slums. The quality of water in hand-dug well is the sole responsibility of the private owners and the government does not conduct any routine checks on the quality produced. The owners of the private wells and the boreholes do not know they are supposed to do a regular water quality check on the water they use and share with other people. It is therefore essential to educate the people on the importance of carrying out water quality analysis on the groundwater. The licensed engineers who drill boreholes should also educate the people on the effects of sitting wells close to toilet facilities or rubbish dumps. Most of the people are not aware of the impacts septic tanks and landfills have on the quality of water obtained. Some argued that water from the ground is always clean.

#### **4.13 Drivers and distribution of Wells**

The spatial distribution of parameters per slum showed that the positions of the wells are influenced by the number of household units and presence of toilet facility. Per the field survey, it was observed that the presence of public toilet facility determines if the area has a borehole. The wells are sited at the premises of the toilet for community use in the case of slum 2 and 3. A household of about 5 to 10 room- units possess a well for the use of house members and nearby people. Another observed factor for well distribution is municipal water network. Areas with constant flow of municipal water use less wells and boreholes especially for drinking. In the same way, communities with less treated water network depend on well water. Flow of treated water determines the use of groundwater. The survey suggests the irregularities in treated water flow is one of the reasons why people drill boreholes for constant water supply. The cost-effective nature of groundwater also influence well distribution in slums and assurance of regular water availability with less cost.

#### **4.14 Groundwater policy of Accra**

A review of three (3) documents pertaining to water policy and groundwater quality was conducted and the outcome stated below;

The review of NWP showed that the national policy focuses only on groundwater recharge in Western, Northern and upper Eastern regions. It probably because those areas have high mineral content. There was exclusion of greater Accra region. NWP provides policy measures for effective

urban water provision but the focus water source is municipal water by GWCL. Under the focus area “Focus area of hygiene and environmental sanitation” the policy provides a clause for water resource pollution which groundwater was vaguely included. Even though the clause does not explicitly mention groundwater, it could apply to groundwater resources. “Preventing pollution of water resources through indiscriminate discharge of wastes (solids/liquids) from domestic commercial and industrial (mining) activities.” The National Community Water and Sanitation project (NCWSP) constructed 113 new boreholes and rehabilitated 3683 boreholes and hand-dug wells in small towns across the country. These projects were initiated to increase access to water by less endowed communities. The boreholes were constructed for the people for use for domestic purposes but there were no quality assurance measures put in place for continuous usage. The management of waste is allocated to local governments by the Ministry of Local Government (MLG). The local governments gain support from Metropolitan, Municipal and District Assemblies under the Environmental Sanitation Policy (ESP). The Water Resources Commission Act of 1996 gives the responsibility of all water resources protection and management to Water Resources Commission (WRC). The focus of the Commission is more on urban water supply by GWCL than on private borehole owners in peri-urban communities. The Public Utilities Regulatory Commission (PURC) is responsible for checking the standards and quality of urban water supply. The PURC does not monitor the quality of groundwater produced in urban centres but focuses on that of GWCL. Ghana Standards Authority (GSA) provides the standard for water quality in Ghana and again focus only on municipal treated water. The exclusion of groundwater quality from the Ghana National Water Policy is putting poor city dwellers at health risks.

The Groundwater Management Strategy (GMS) was developed in 2011 by the WRC to incorporate active groundwater policies, promote groundwater sustainability and safety of users. The GMS has a vision 2020 of achieving three (3) goals which highlights exchange of groundwater data and information, strengthen groundwater policies & frameworks and engagement of all stakeholders in groundwater management (Ben Y. Ampomah, 2011). The strategy highlights conduction of groundwater observation in the Northern region by Water Research Institute (WRI). The groundwater observation is limited to only the Northern region which is also curtailed by financial constraints. The strategy is limited to only a region of the country and it should include all regions especially slums that depend on groundwater for survival.

The National Drinking Water Quality Management Framework of 2015 provides quality framework for drinking water. A clause was provided for preventive measures in terms of groundwater contamination. It highlights the need to create buffer zones between wells and contamination sources. The framework considers groundwater as water in a confined aquifer. Therefore, the risk of contamination is low provided the water is protected by a well head and a safe medium of transport and storage (Ministry for Water Resources, 2015). Due to the framework's assumption of low risk of contamination in confined aquifers, prevention provision was only made for transport and storage of groundwater. The framework should consider there is high possibility of contamination due to locations of wells and sanitation vises. Also, continuous pumping of groundwater could introduce activation of naturally occurring elements beyond safe limits.

## CHAPTER FIVE

### 5.0 SUMMARY, CONCLUSION AND RECOMMENDATION

#### 5.1 Summary

The study was conducted to examine the effects of urbanization on groundwater quality in African cities. A case study of Accra was selected within which five (5) major slums were taken as specific case studies. The slums include Nima, Sabon Zongo, Chorkor, Jamestown and Pantang-Abokobi all in Accra Metropolis and Accra East. A total of twenty (20) samples were collected from the five (5) different slums. This implies four (4) samples were taken from each community. The samples were taken to water quality laboratory to carry out physicochemical and microbiological analysis. A questionnaire was administered in the slums to in other to ascertain basic information regarding the groundwater and its uses.

The outcome of the research is categorized under five objectives; the first objective entails collection of samples from different slums and mapping of the well positions using GIS. The position of the wells and boreholes were taken with a GPS and the coordinates were used to generate a map in ArcGIS with Geostatistical Analyst Extension tool. The maps showed the concentration of each water quality parameter in every slum. It was observed from the maps that, slum 3 showed the highest concentrations of salts (Magnesium(255.00mg/L), Calcium(462.50mg/L), Chloride(1063.4mg/L), sodium(690.16mg/L) and Total dissolved solids(1862.4mg/L). Slum 4 showed the least concentration of salt producing parameters followed by slum 5, slum1 and slum 2. Nitrate levels were predominantly high in slum 1, 2 and 4 with concentrations of 67.430mg/L, 54.120mg/L, and 73.480mg/l respectively. Cases of increased lead concentrations were also noticed in all slums except slum 2 which recorded zero concentration of lead. All the wells showed levels of bacterial contamination

The second objective is to determine the microbiological composition of the samples taken. The study showed that all the samples from the various slums have E. coli and Total Coliform present in the water. Even though coliform bacteria were present in all the samples, some slums recorded higher coliform counts than others. It was also observed that hand-dug wells have more coliform bacteria than boreholes. The mean E. coli count per slum is 18.25CFU/100mL, 149.75CFU/mL, 12.50CFU/100mL, 89.50CFU/mL, and 249.00CFU/100mL for slum 1 to 5 respectively. The results showed relatively low E. coli counts from boreholes with tap compared the ones from hand-dug wells. The trend in E. coli count per slum is slum 5> slum 2> slum 4>slum1>slum3. The mean

total coliform count was used to determine the presence of any other coliform bacteria in the groundwater samples. The average total coliform for Slum 1, slum 2, slum 3, slum 4 and slum five are 90.75CFU/100mL, 237.75CFU/100mL, 162.75CFU/100mL, 185.25CFU/100mL and 490.25CFU/100mL. Following the same trend as the E. coli, higher coliform counts were noted in hand-dug wells than boreholes but the total coliform of slum 3 is higher than that of slum 1 even though slum 3 had lower E. coli. This shows the presence of more coliform bacteria in the borehole. The slums closer to major landfills showed greater bacterial contamination than those far away from rubbish dumps.

Thirdly, an objective is to determine the physicochemical contamination of the groundwater samples. The parameters studied include pH, turbidity, electrical conductivity, total hardness, TDS, TSS, calcium, magnesium, sodium, chloride, iron, fluoride, sulphate, zinc, lead, arsenic, manganese, ammonium, phosphate, nitrate and nitrite. Slum 3 and 2 have high levels salts producing parameters with slum 1, 3 and 5 exposed to manganese. The nitrate levels of slum 1, slum 3 and 4 are Alarming. All slums are experiencing lead poisoning except slum 2.

The last but one objective is to compare the quality indices to the WHO standard guidelines. In terms of the physical parameters; pH for slum 1, slum 3 and slum 5 have exceeded the WHO guideline while the rest are within the acceptable range. Total hardness, calcium, magnesium, sodium, and chloride have exceeded the WHO limit for slum 2 and 3. The nitrate values recorded in slum 1, 3 and 4 are beyond the WHO guideline and continuous intake of the water in those communities put the indigenes at the risk of cancer and blue baby syndrome in children and pregnant women. Another parameter which is beyond the acceptable value is manganese. Traces of the element in slum 1, slum 3 and slum 5 are high compared to the WHO limit and puts consumers of the water at a health risk. The last chemical parameter is lead and the heavy metal is on the red list of WHO and all the slums have exceeded the required limit except slum 2. This implies the rest of the four slums are experiencing lead poisoning. The rest of the physicochemical parameters are all within acceptable range except electrical conductivity which has exceeded the limit for slum 2 and 3. TDS is also beyond the required standard in slum 3. In terms of microbial contamination, all the slums have exceeded the standard WHO value for coliform bacteria presence in groundwater.

The final objective of the study is to develop a policy framework to be implemented in the affected communities using the contaminated groundwater. A critical study of Ghana's current regulation

on the use of groundwater and policy was conducted and gaps were filled with possible solutions based on the loop holes in the existing policies and the discoveries made from this study.

## **5.2 Conclusion**

Following the deductions made from the study, it can be concluded that the location of boreholes and wells in slums within the city of Accra have negative impacts on the quality of groundwater. The living and sanitation conditions of urban dwellers in slums determine the purity of groundwater. Groundwater from all the selected slums within Accra have coliform bacteria contamination. This is attributed to leaching of sewage from pit latrines and landfills which were very common in the slums. Microbiological indicators such as *E. coli* and total coliform are higher than the WHO accepted value and thereby render the groundwater in Nima, Sabon Zongo, Chorkor, Jamestown and Pantang-Abokobi unsafe for human consumption. The studies have confirmed that the bacteriological contamination of hand-dug wells is higher than boreholes with a tap. Further studies into the physicochemical analysis of samples indicates groundwater in coastal slums are experiencing salt water intrusion and drinking of such water is not healthy according to the WHO safety guidelines. There is also massive exposure to nitrates and manganese in majority of the five slums under study. The study also discovered lead poisoning in all the slums except one and this requires immediate rectification as lead is considered radioactive and a threat to public health. The users of groundwater in slums have low knowledge on how the siting of wells and improper sanitation facilities affect the quality of groundwater. Users of groundwater in urban slums have less interest in checking the quality of water used for domestic purposes.

This study has provided geographical location of wells and the level of contamination per slum which can serve a guide for groundwater quality regulation in the near future. Ghana's policy on Groundwater use does not regulate and monitor the quality of groundwater sold to people by private owners.

A suggested policy framework built for the problem areas in Accra could be implemented in these urban slums in order to rectify the effects of urbanization on groundwater.

### **5.3 Recommendations**

Based on the outcome of the study, the appropriate stakeholders should take the following actions:

1. The water quality data from the findings should be used by the Water research Institute in other to facilitate groundwater quality monitoring in Accra.
2. Groundwater management strategy of 2011 should incorporate monitoring of groundwater quality not by Community Water and Sanitation Agency but the quality check should be conducted by Ghana Water Company Limited in collaboration with Ghana Standards Authority. The exercise should be conducted at least twice a year to ensure the water quality meet the standards of WHO.
3. The health directorate of the Accra Metropolis should conduct a health screening exercise in all the communities studied for immediate intervention. This action is time sensitive for areas experiencing lead poisoning.
4. The GWCL should ensure constant municipal water supply in slum communities irrespective of their settlement structure. There should be constant flow of water in the community in other to prevent overdependence on groundwater especially for communities such as Chorkor that is experiencing salt water intrusion.
5. Regulations should be put in place by the Water Resources Commission (WRC) to conduct monitoring and evaluation before boreholes are sited by private companies. The cases of necessary borehole siting, the borehole should be sited at a higher elevation than sewage facilities. Buffer zones should be created between boreholes and rubbish dumps.
6. The Ministry of Sanitation should ensure improved sanitation systems in slums as it is in elite urban centres. These include engineered landfills, proper toilet facilities and sewage networks. Solid waste disposal points should be provided for coastal slums in other to prevent dumping of rubbish on the sea shore.
7. Routine sanitary check should be conducted regularly on wells and boreholes. This is to check the living conditions of the wells and protection from external anthropogenic contamination.
8. The government of Ghana should partner with private companies in other to provide affordable housing units for the poor and less endowed people who are crowded in unsanitary slums.
9. Opinion leaders in slum communities should conduct regular educative programs for slum dwellers. This is to increase exposure on the impacts of good sanitation practice on groundwater quality.

10. The National Water Policy of 2007 should be reviewed and updated to include in-depth policies on groundwater resource protection and quality

11. The Groundwater Management Frameworks of 2011 and National Drinking Water Quality Framework 2015 should incorporate a nation-wide coverage of groundwater management and quality indicators.

### **5.3.1 Suggested Policy Brief**

#### **Alarming state of Groundwater quality in Accra slums; A call to Action**

##### **Executive Summary**

The general sanitation status of some selected slums in Accra has affected the groundwater quality by causing both bacteriological and chemical contamination. Residents in these urban slums in Accra depend on groundwater for domestic purposes. Safety and quality of the water is essential to their health as contaminated water contains disease causing organisms. Siting of wells and boreholes far away from latrines, septic tanks and landfills protects the environment for ensuring groundwater quality. This policy brief highlights the problem areas and the plausible ways to ensure groundwater safety in Nima, Sabon Zongo, Chorkor, Jamestown and Pantang- Abokobi.

##### **Introduction**

All urban dwellers have the right to quality water irrespective of their settlement structure or standard of living. In the case of less endowed Accra city dwellers, access to quality water is curtailed as they are not connected to municipal water or unable to afford when connected. Dependence on groundwater provides a cheaper option for water access but quality is compromised due to improper sanitation in the slums. The study showed that groundwater in the slums are faecally contaminated due to the locations of the wells. Landfills are the major contributors coupled with sewage leaching. The contamination resulted in nitrate exposure and lead poisoning which needs an urgent solution because of the dangerous health consequences. Assurance of groundwater quality is only possible if there are provision of proper sanitation systems and enforcement of WHO standards in siting of wells.

##### **Groundwater quality and sanitation**

The groundwater sources of the slums are situated at non- acceptable locations in reference to poor sanitation systems. The outburst of all kinds of sanitation setbacks have contaminated the water in terms of nitrate exposure, lead poisoning, and faecal contamination. In the same way, slums on



the Atlantic coast are exposed to salt water intrusion. The Ministry of Sanitation should enforce initiatives to provide improved sanitation facilities in urban slums of Accra. The Ministry should ensure that all landfills are engineered in other to prevent leaching of sewage and chemicals into groundwater. Rubbish collection trucks should also be provided at vantage points in slums to enable easy collection to an engineered site. Another groundwater quality issue discovered in the study is the location of wells. The Ministry of Sanitation (MOS) in collaboration with Water resources Commission (WRC) should enforce regulations to monitor private borehole drilling companies. This is to ensure that wells and boreholes are sited far away from septic tanks, rubbish dumps and pit latrines. Proper toilet facilities such as water closets and pour-flush systems should be provided in urban slums to replace conventional pit latrines. In other to prevent outburst of diseases from contaminated water, it is important that the government of Ghana provides alternative water source for these people while putting measures in place to resolve the current groundwater contamination.

### **Inclusive growth**

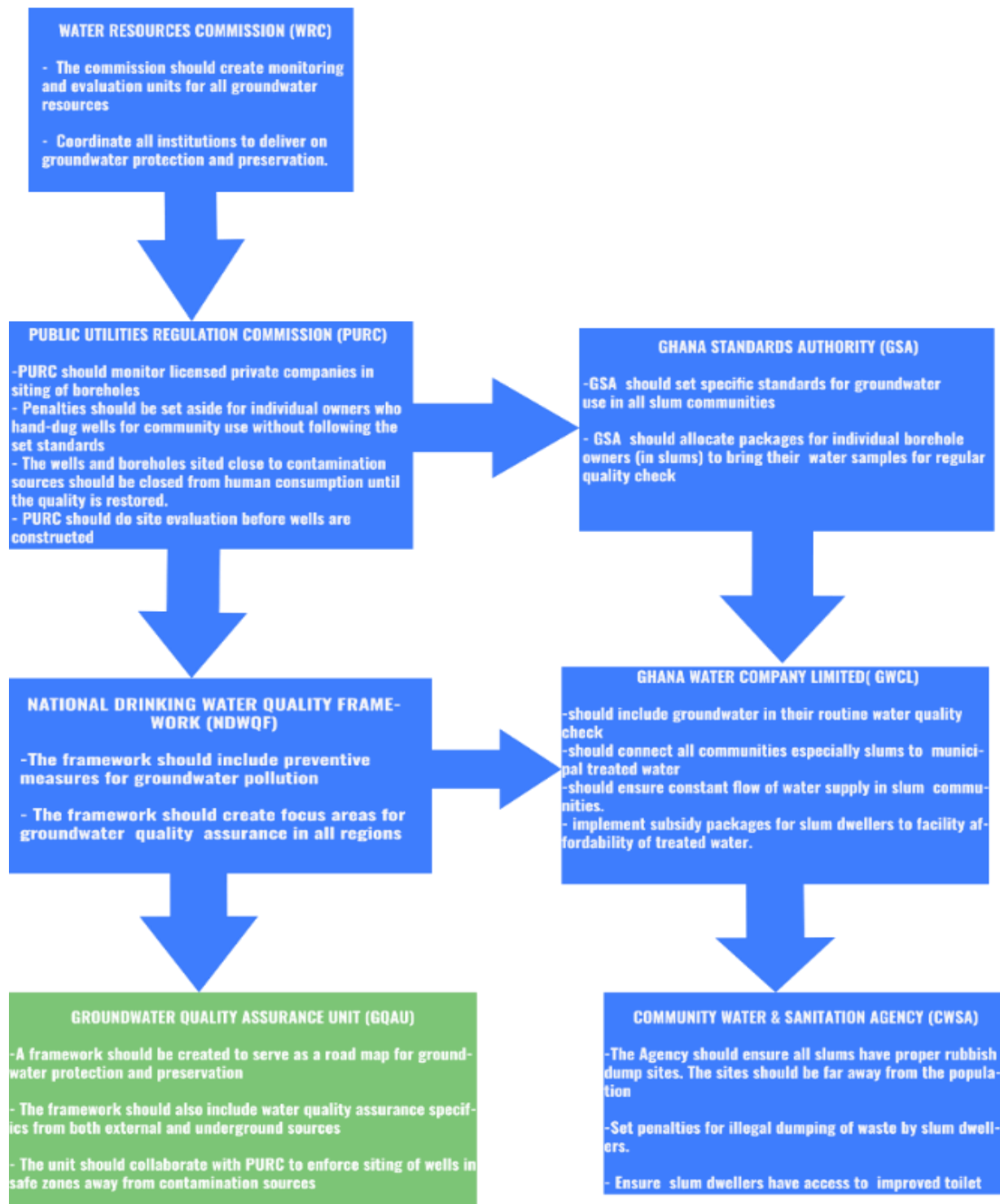
The urban centres of the city of Accra are fully connected to municipal treated water while some urban slums lack municipal treated water. A typical case is Pantang- Abokobi landfill community. The gap between urban dwellers and slum dwellers should be closed in terms of quality water. All communities should have access to municipal treated water and dependence on groundwater should not be the only choice but an option. Ghana Water Company Limited should put subsidy packages in place for slums dwellers that cannot afford the municipal water. The Water Resources Commission should enforce regulations that ensures there is constant monitoring of groundwater quality in all areas within the city of Accra. The areas of bacterial contamination, lead poisoning, and nitrate exposure highlighted in the study should be addressed as soon as possible. Health screening should be conducted in all five slums to curtail future health problems. Effective measures by the Water Resources commission (WRC) should be taken to ensure groundwater quality assurance. Slums that depend on contaminated water for consumption are at the risk of health complications. It is therefore important that the government puts measures in place to avoid these health problems as it exerts financial pressure on the nation and a burden to World Health Organization as whole.

### **Education and Awareness creation in slum communities**

The populace of urban slums lack information and knowledge on how their daily sanitation, practices affect groundwater. In- depth knowledge on the impacts of improper sanitation on groundwater quality for all users of groundwater is needed. Ministry of Sanitation, Water Resources Commission, and all stakeholders should organize rallies, workshops and public lectures on the importance of good sanitation in slums. Education forums should be made available for private borehole drilling companies on siting of wells within the slum communities.

## Institutional Policy Framework

**Table 6.1: Institutional policy Framework**



(Author's creation 2019)

## **Conclusion**

Overall, it was deduced that even though, groundwater is a cheaper option in urban water access, the environmental hazards from anthropogenic sources curtail quality assurance. Practice of good sanitation aids in protecting groundwater from contamination but siting of wells away from pollutant sources is of importance. Provision of affordable alternate drinking water source for urban slums is essential in reducing health consequences of drinking contaminated groundwater

### **1.5 5.4 Areas for Further research.**

The study was limited to one season of water sampling. More research should be conducted where samples are collected in both dry and wet seasons. This will ascertain the impacts of climate on movement of contaminants into groundwater. Also, the research should be carried out in various cities in Africa in order to establish the effects of urbanization on groundwater quality within the African continent.

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## APPENDIX

### A. Questionnaire

#### Questionnaire

Questionnaire Number. ....

1. Name of slum.....
2. House number.....
3. Source of water supply.....
4. Human and solid waste system available.....
5. Does living in this community affect your accessibility to clean water? ☐ yes ☐ no
6. If yes, what kind of water do you use ☐ Borehole ☐ Pipe water ☐ Dug Well ☐ Other ☐
7. Type of ground water in the house ☐ borehole ☐ well
8. Do you share the water with other neighbours? ☐ Yes ☐ No
9. Proximity to industry, pit latrine or landfill..... metres
10. How long has it been in existence .....? years
11. What do you use the water for? (Tick all that apply) - ☐ drinking ☐ cooking ☐ bathing ☐ washing
12. ☐ other Specify .....
13. Have you noticed any changes in the water during the period of usage? ☐ Yes ☐ No
14. If yes, Specify.....
15. Have you checked the water quality before ☐ Yes ☐ No
16. If yes, how often? (Tick what applies)
17. ☐ yearly ☐ every five years ☐ other (please specify)
18. If yes, when, and where was it last checked? .....years
19. ....months..... (respectively)
20. 18. If no, reason? .....

B.

Field work



**Plate 8.1: Hand-dug well used in Pantang-Abokobi Landfill community**

(Author's Fieldwork 2019)



**Plate 8.2: Well at Nima Slum (Author's fieldwork 2019)**





**Plate 8.3: Water Sampling at Chorkor community**

(Author's Field work 2019)